Telcordia Technologies

Performance from Experience

Telcordia
Notes on the Networks

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Related documents:

SR-NOTES-SERIES-01, *Telcordia Notes on the Synchronous Optical Network (SONET)*
SR-NOTES-SERIES-02, *Telcordia Notes on Dense Wavelength-Division Multiplexing (DWDM) and Optical Networking*
SR-NOTES-SERIES-03, *Telcordia Notes on Number Portability and Number Pooling*
SR-NOTES-SERIES-04, *Telcordia Notes on the Evolution of Enhanced Emergency Services*.

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12. Distribution

12.1 Introduction

The distribution network is the part of the overall telephone network that connects the switched and interoffice networks with individual customers. An integral part of the distribution network is the loop, which connects the customer to the local Central Office (CO), thus providing access to the interoffice network.

12.1.1 Feeder and Distribution Plants

The distribution network is divided into two major parts: feeder and distribution plants. Figure 12-1 shows a simplified schematic representation of the feeder route, its branch or subsidiary feeder routes, and distribution routes.

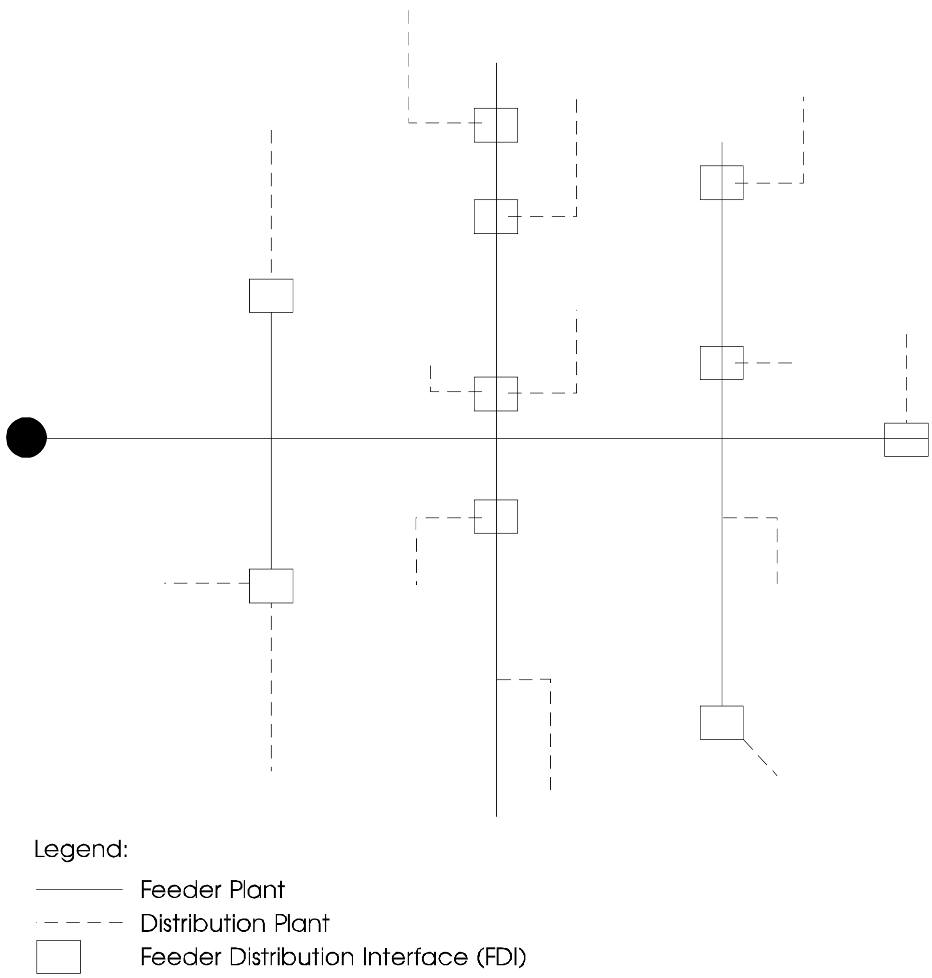


Figure 12-1. Feeder and Distribution Plants

12.1.1.1 Feeder Plant

The feeder portion of the present LEC network is composed of fiber-optic cables, various gauges of copper cables, T1-carrier lines, and radio. It can transport analog and digital signals that are multiplexed together to derive high bit rates, which characterize the modern feeder network. Analog-to-digital conversion is achieved through Digital Loop Carrier (DLC) systems, described in detail in Sections 12.6 and 12.7, which are also the first step in the multiplexing process. Both the DLC and multiplexer systems are strategically placed in proximity to the Feeder Distribution Interface (FDI).

The cable pair or channel capacity of the feeder plant decreases (tapers) as its distance from the local central office increases. As the feeder distributes facilities along the way between the local central office and the customers, the cable pair capacity decreases. The feeder routes provide large numbers of cable pairs or channels from the central office to strategic remote locations called serving areas, part of the Serving Area Concept (SAC). These serving areas include cross-connect points in the network between the feeder plant and the distribution plant, at the FDI.

To meet future service needs, sections of the feeder plant are designed to be augmented periodically. Typical relief time periods for feeder plants vary between 4 and 15 years, depending on individual company needs and practices. Local geography and customer or facilities locations determine the placement of feeder routes, including below-ground or aerial facilities. Many feeder routes parallel major traffic highways. Multiple connecting subfeeders, or branch feeder routes, are derived from a relatively small number of main feeder routes leaving a local central office. Because of the high number of cables involved, and the need for periodic addition of cables, most below-ground feeder plants are in underground conduit structures for ease of placement and replacement.

12.1.1.2 Distribution Plant

The distribution plant consists of small cables/systems that cross-connect the feeder plant to the customer. This plant is designed to meet the greatest expected customer demand in an area for the life of the plant. In the distribution facilities, copper cables of 26, 24, 22 (and rarely 19) gauge predominate. Distribution network design requires more distribution pairs than feeder pairs; distribution networks contain more distribution cables than feeder cables. Most distribution plants include either direct-buried or aerial cable, with the ultimate needs installed initially.

12.1.2 Multiple, Dedicated, and Interfaced Plant

Distribution plant design treats loops on an aggregate instead of an individual basis, so large composite cross-sections of facilities are designed with similar transmission characteristics. This simplifies distribution network design, especially when several gauges of cable are used.

The major distribution network designs that have been used by the LECs include multiple, dedicated, and interfaced plant. Carrier Serving Area (CSA) design is discussed later in this section.

Multiple plant design extended the number of customers that could be served by a feeder pair through multipling (splicing two or more distribution pairs to a single feeder pair). This procedure has the advantage of providing flexibility to accommodate future assignments by providing multiple appearances of the same loop pair at several distribution points. However, adding new feeder cables causes line and station transfers and cable-pair transfers to relieve the distribution cables. Multiple plant design was largely replaced by dedicated plant design because of the labor intensity of adding to or changing existing plant and customer demands to convert from multiple-party line to single-party line service.

Dedicated plant provides a permanently assigned cable pair from the central office Main Distributing Frame (MDF) to each customer. Dedicated plant largely eliminates expensive transfers of lines, stations, and cable pairs. Because of customer demand for additional service, the use of dedicated plant design for new construction has, in turn, been generally superseded by interfaced plant.

Interfaced plant uses a manual cross-connect and demarcation point, the FDI, between the feeder plant and distribution plant. The cross-connect, or interface, allows any feeder pair to be connected to any distribution pair. This increases flexibility and reduces outside plant deployment and labor costs. Compared to both multiple and dedicated plant, interfaced plant provides greater flexibility in the network and represents the present conventional (metallic pair) distribution plant design philosophy.

12.1.3 Distribution Network Design

To help achieve acceptable transmission in the distribution network, design rules are used to control loop transmission performance. Loops are designed on a global basis to guarantee that loop transmission loss is statistically distributed and that no single loop in the distribution network exceeds the signaling range of the central office.

Prior to 1980, loops were usually designed using one of the following design plans: Resistance Design (RD), Long-Route Design (LRD), or Unigauge Design (UG). The most common current design plans applied only on a forward-going basis (retroactive redesign is not generally deployed) are the following: Revised Resistance Design (RRD), Modified Long-Route Design (MLRD), and Concentrated Range Extender with Gain (CREG).[1]

RRD guidelines recommend that loops 18 kft in length or less, including bridged-tap[2], should be nonloaded and have loop resistances of 1300 Ω or less; loops 18 kft

1. See Section 7, “Transmission”, for additional information regarding the design rules for these plans.

to 24 kft in length (including bridged-tap) should be loaded and have loop resistances less than or equal to 1500 Ω; loops longer than 24 kft should be implemented using Digital Loop Carrier (DLC) as first choice, or by CREG or MLRD as second choices.

RRD limits bridged-tap to less than 6 kft for nonloaded cable. For loaded cable, the end section plus bridged-tap must be greater than 3 kft but less than 12 kft.

MLRD applies to the design of loops having loop resistances greater than 1500 Ω but less than or equal to 2800 Ω. All cables should be loaded, and MLRD recommends that two cable gauges be used along with the required range extension and gain. The bridged-tap and end-section requirements are compatible with RRD for loaded cable.

The CREG plan allows for increased use of finer gauge cable facilities by providing a repeater behind a stage of switching concentration in the central office. In this way, the range-extension circuitry is shared rather than dedicated in each loop. CREG design applies to loops having loop resistances of 0 to 2800 Ω. Its loading, bridged-tap, and end-section requirements are compatible with RRD and MLRD, unlike the UG plan that it replaces.

Current design plans offer improved transmission performance over the old plans, while all plans provide approximately the same minimum loop transmission loudness ratings.

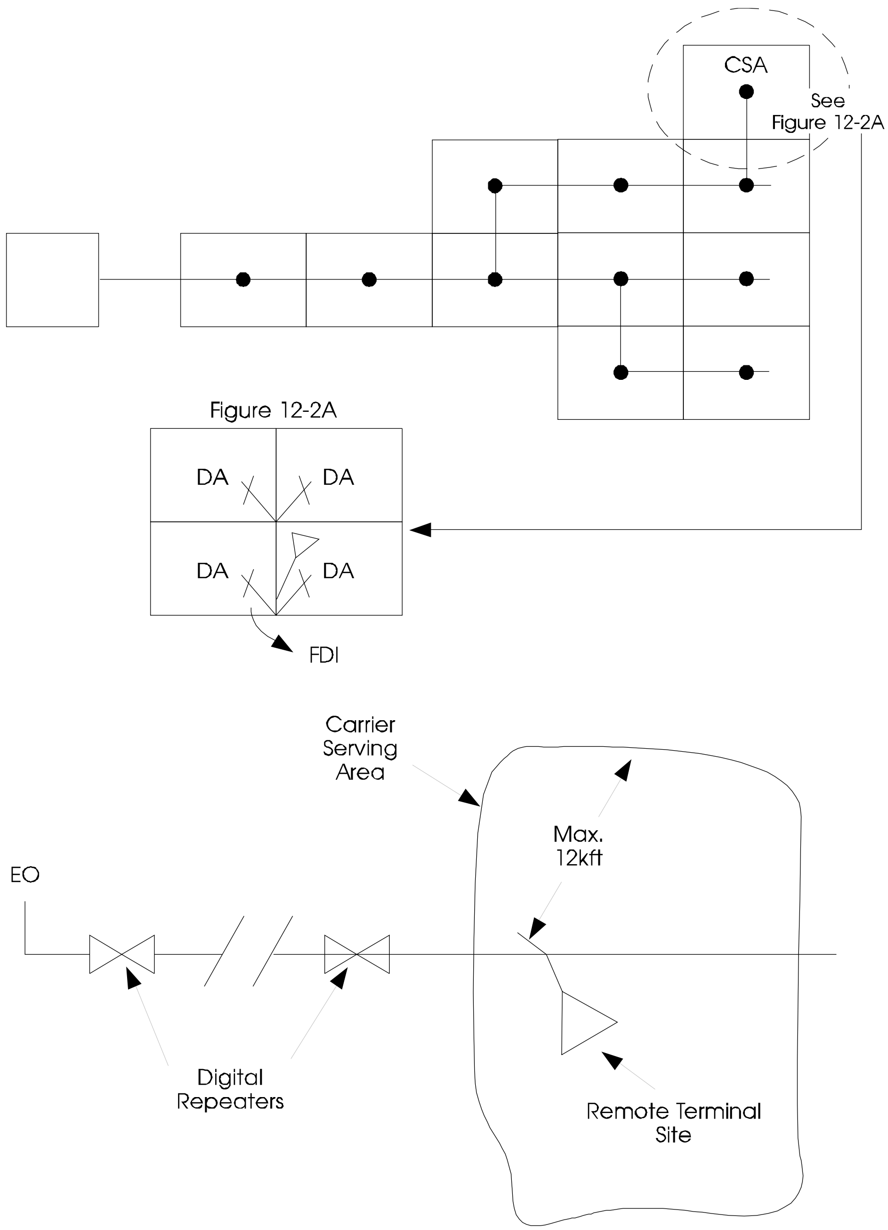
12.1.4 Carrier Serving Areas

The evolution of the network that can provide digital services using distribution plant facilities has led to the development of the CSA concept. A CSA is a geographical area that is, or could be served by, a DLC from a single remote terminal site and within which all loops, without any conditioning or design, are capable of providing conventional voice-grade message service, digital data service up to 64 kbps, and some 2-wire, locally switched voice-grade special services (see Figure 12-2). The maximum loop length in a CSA is 12 kft for 19-, 22-, or 24-gauge cables and 9 kft for 26-gauge cables. These lengths include any bridged-tap that may be present. The maximum allowable bridged-tap is 2.5 kft, with no single bridged-tap longer than 2.0 kft. All CSA loops must be unloaded and should not consist of more than two gauges of cable.

The area around the serving central office within a distance of 9 kft for 26-gauge cable and 12 kft for 19-, 22-, and 24-gauge cables, although not a CSA, is compatible with the CSA concept in terms of achievable transmission performance and supported services.

In addition to the CSA concept, the LECs also use the Serving Area Concept described above.

2. A bridged-tap is any branch or extension of a cable pair beyond the point where it is used and in which no direct current flows when a station set is connected to the pair in use.



Legend:

CSA	=	Carrier Serving Area
DA	=	Distribution Area
EO	=	End Office
FDI	=	Feeder Distribution Interface

Figure 12-2. Carrier Serving Areas

12.2 Metallic Loop Conditioning

The transport of digital signals carrying 56 kbps or more bandwidth may require additional design considerations. Restrictions on loss and bridged-tap, removal of build-out capacitors, introduction of echo cancelers and line equalizers, and coordination with other services in the same cable may be required.

New digital signal-processing techniques, such as those used in the Integrated Services Digital Network (ISDN) Basic Rate Access (BRA) Digital Subscriber Line (DSL), permit the deployment of 160-kbps signals on most nonloaded loops ($\leq 1300\ \Omega$) without any conditioning.

Copper cables are the most widely deployed transmission media today. However, fiber-optic cables are usually the media of choice in the feeder plant for deployment of DLC. Fiber cables in the distribution plant may also be needed to handle the increasing bandwidth required for future services (see Section 12.12). Radio transport is also used in selected routes.

12.3 Loop Surveys

Three comprehensive surveys of Bell Operating Company (BOC) subscriber loops have been conducted in the last 35 years.[3] The first comprehensive survey was made in 1964, the second in 1973, and the third in 1983. A more limited survey, the 1987 to 1990 Digital Access Survey (DAS), obtained more specialized information about DLC loops, and loops in potential broadband wire centers. (A potential broadband wire center is a wire center serving an area containing establishments that have high potential to use new loop technologies for subscribing to future broadband services; i.e., wire centers serving large business customers.) The most recent loop survey is an analysis of 1993-1998 loop facility infrastructure data reported by LECs to the Automated Reporting Management Information System (ARMIS), a data collection system managed by the Federal Communications Commission (FCC).

Results obtained from these surveys continue to be of value for planning and network management. Recent technological advances and the increasing number and types of services, coupled with the introduction of electronics (particularly digital carrier technology and fiber-optics) into the loop plant, have a significant impact on the assumptions that distribution network planners and engineers use to improve the network.

This section describes:

1. The principal results of the 1983 Loop Survey
2. The objectives of the 1987 to 1990 DAS and a summary of the corresponding results. (This information provides a statistical profile of the loop network to aid the planning and engineering process.)
3. An analysis of 1993-1998 ARMIS database information reported by LECs.

12.3.1 1983 BOC Survey Results

The following terms are used in the 1983 BOC survey results. Figure 12-3 illustrates terms describing the distribution plant.

- *Total length* of the loop is the sum of all cable segment lengths, including all the bridged-taps.
- *Working length* of the loop is the sum of all cable segment lengths from the central office to the customer's Point of Termination (POT). Working length must be less than or equal to the *total length* of the loop.
- *Service* refers to the type of service provided by the sampled pair (business or residence service and whether residence or business service is a special service).

3. Other entities conduct similar surveys. The methodologies and results of these surveys may differ from the BOC surveys discussed herein.

- *Drop (or service wire) length* is an estimate of the total entrance wire length from an outside terminal location to the customer.

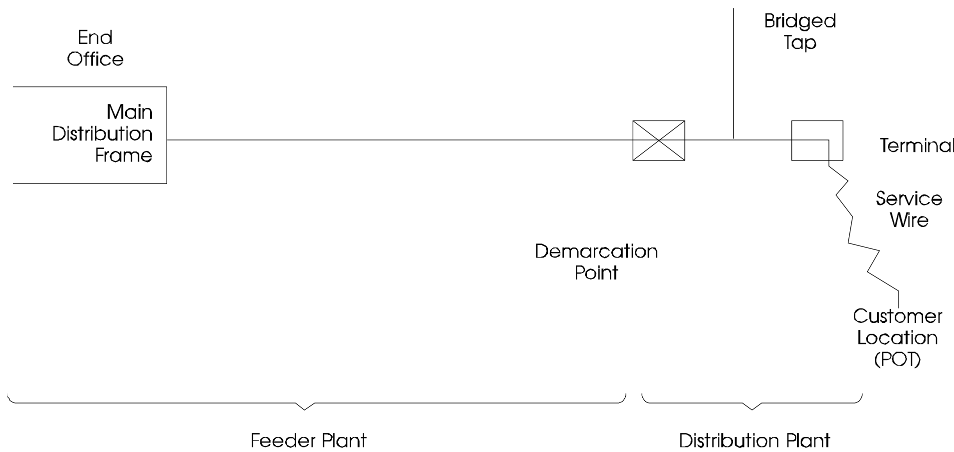


Figure 12-3. Representation of Loop

12.3.1.1 Composite

Table 12-1 contains the summary statistics of lengths for all the sampled working pairs. In this discussion, average and mean are synonymous. The average total length for the sampled pairs is 12,113 ft; the average working length is 10,787 ft; and the average bridged-tap length is 1,299 ft. The average airline distance is 7,692 ft; the average drop or service wire length is 73 ft; and the average planned ultimate route length is 29,850 ft. These last three values are not shown in the table.

Table 12-1. 1983 Loop Survey — Length Statistics

(Sample Size 2,290)	Minimum ft	Maximum ft	Mean ft	SDM* ft
Total Length	250	114,838	12,113	196
Working Length	186	114,103	10,787	188
Total Bridged-Tap	0	18,374	1,299	34

*SDM (Standard Error of Mean)

Table 12-1 also contains the standard errors in the estimation of means for each of these statistics. To calculate a 90-percent confidence interval for the sample, multiply 196 (the Standard Error of Mean [SDM] for total length from Table 12-1) by 1.645 (the 90-percent confidence coefficient). The resulting 90-percent confidence interval for the sample mean of the total length is 12,113 ± 322 ft. This is interpreted to mean that, with a probability of 0.9, the mean total length of all working pairs lies in this interval. The confidence coefficient for the 99-percent confidence interval is 2.58, and for the 80-percent interval, 1.28. These coefficients can be used to determine the desired confidence interval. Figures 12-4, 12-5, and 12-6 present the distribution of total, working, and bridged-tap lengths as determined by the 1983 survey.

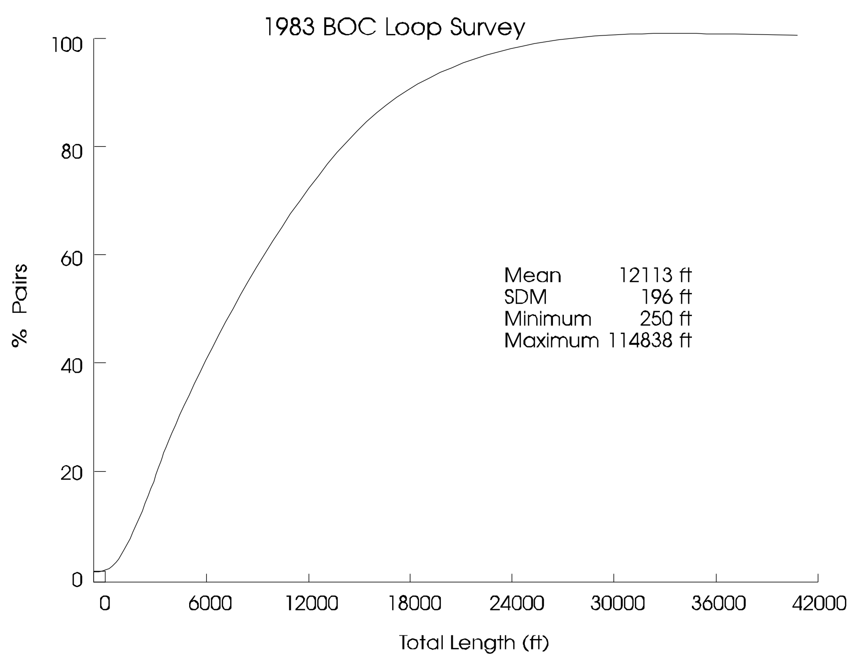


Figure 12-4. Total Length Distribution

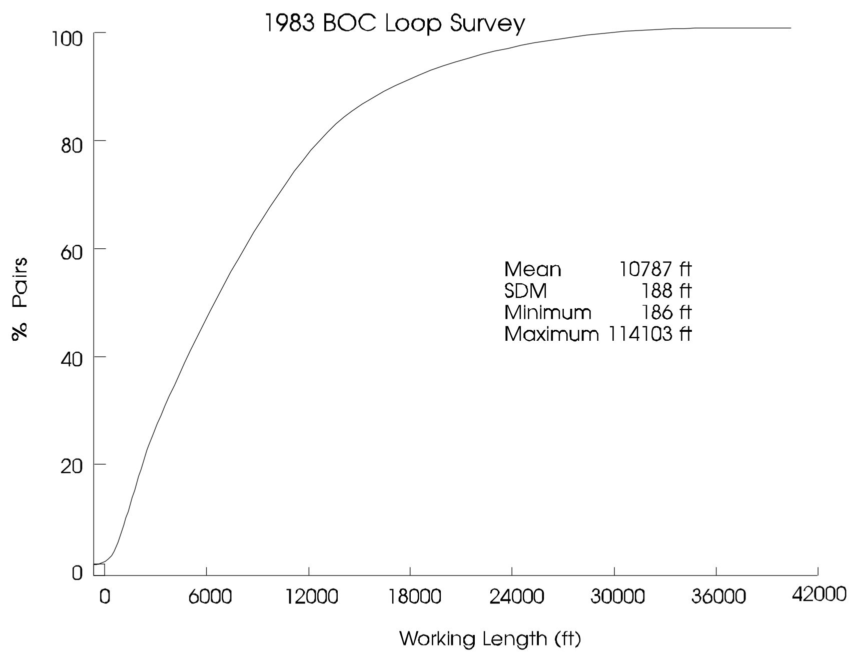


Figure 12-5. Working Length Distribution

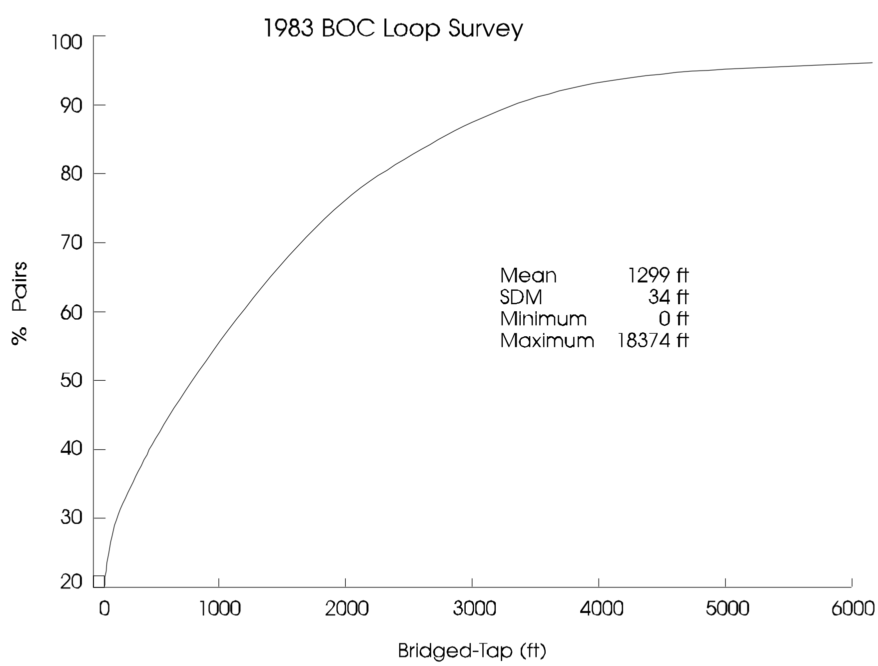


Figure 12-6. Bridged-Tap Length Distribution

Table 12-2 shows a comparison between the working-loop lengths of working pairs from 1964, 1973, and 1983 BOC loop surveys. Residence pairs from the 1983 survey are compared to the total sample results from the earlier surveys. This comparison is made because earlier surveys emphasized residential main stations. Working-loop lengths show an increasing trend while an averaged bridged-tap length shows a decreasing trend over these years.

Table 12-2. 1964, 1973, 1983 Loop Surveys — Comparison of Lengths

	Total	**Total**	**Residence**
Year of Survey	1964	1973	1983
Average Working Length	10,613 ft	11,413 ft	11,723 ft
Average Total Bridged-Tap	2,478	1,821	1,490
Average Airline Distance	7,758	8,410	8,387

Figure 12-7 shows the cumulative percent of the cable gauges all the way from the central office. The statistics are given as a function of distance from the central office. The gauge distribution in Figure 12-7 was derived by determining the gauge of each working pair sampled at 500-ft intervals from the central office. This figure shows that as one moves away from the central office, the gauge becomes more and more coarse. For example, at a distance of 10 kft from the central office, the approximate cable mix is 30 percent for 26 gauge, 51 percent for 24 gauge, 18 percent for 22 gauge, and 1 percent for 19 gauge.

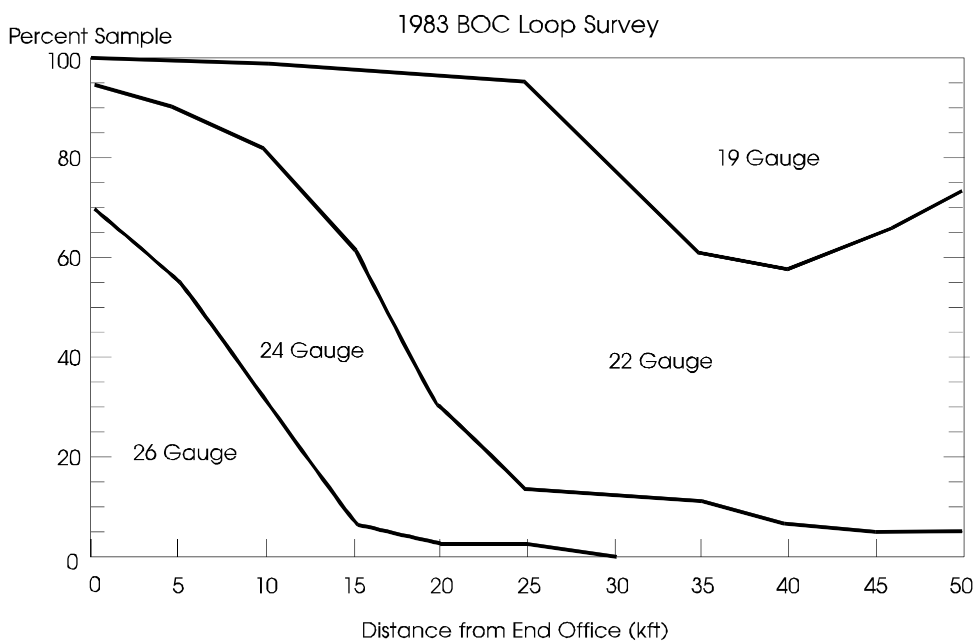


Figure 12-7. Cable Gauge Distribution (Not Including Bridged-Taps)

Figure 12-8 shows the cable structure distribution as a function of distance from the central office. This information was also derived by determining the structure type at 500-ft intervals from the central office. Aerial cable is mounted on utility poles, underground cable is in conduits, and buried cable is placed directly in the ground. This figure shows that more than 85 percent of the cable structure is underground close to the central office. It also shows that the farther the distance from the central office, the more buried and aerial facilities predominate. For example, at a distance of 10 kft from the central office, about 53 percent of the structure is underground, 16 percent is buried, and 31 percent is aerial.

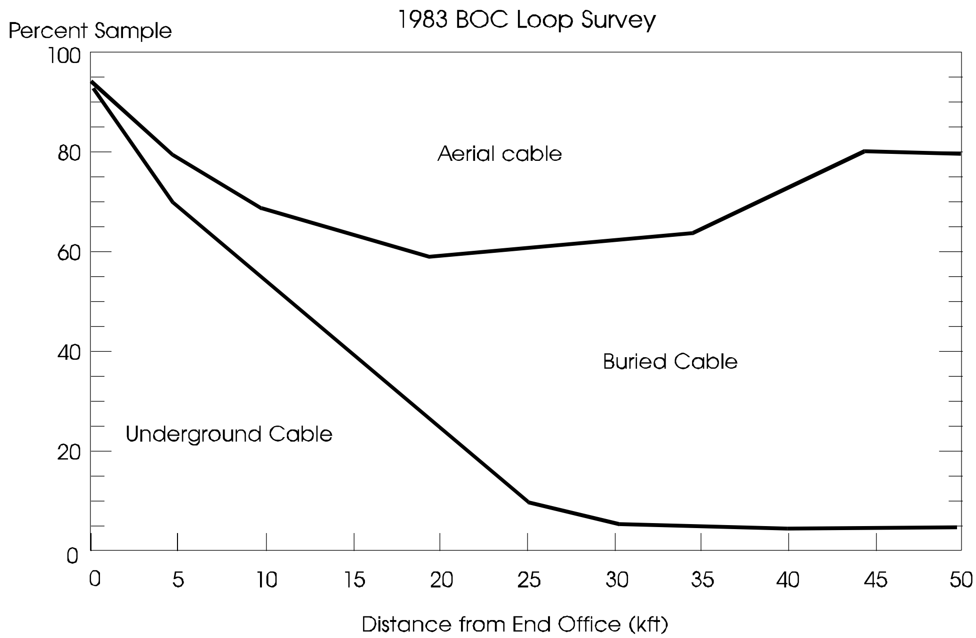


Figure 12-8. Cable Construction Distribution (Not Including Bridged-Taps)

12.3.1.2 Residence

Table 12-3 contains summary statistics of lengths of sampled residence working pairs. Sampled residence pairs have an average total length of 13,190 ft and an average working length of 11,723 ft. The average bridged-tap length is 1,490 ft. Figures 12-9 through 12-11 present cumulative distribution plots for these statistics.

Table 12-3. 1983 Loop Survey — Residence Length Statistics

	Minimum ft	Maximum ft	Mean ft	SDM ft
Total Length	495	114,838	13,190	245
Working Length	186	114,103	11,723	236
Total Bridged-Tap	0	18,374	1,490	44

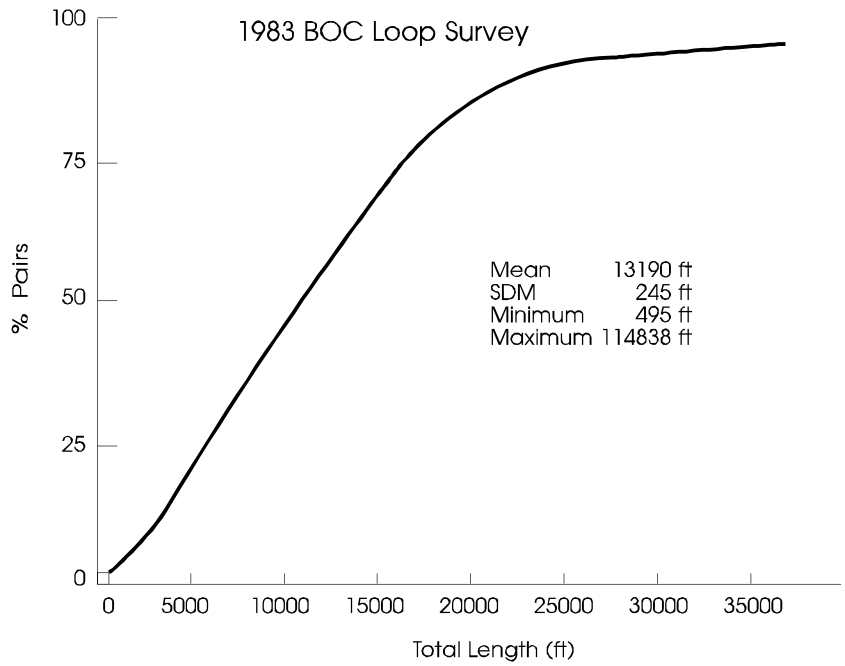


Figure 12-9. Total Length Distribution Residence Loops

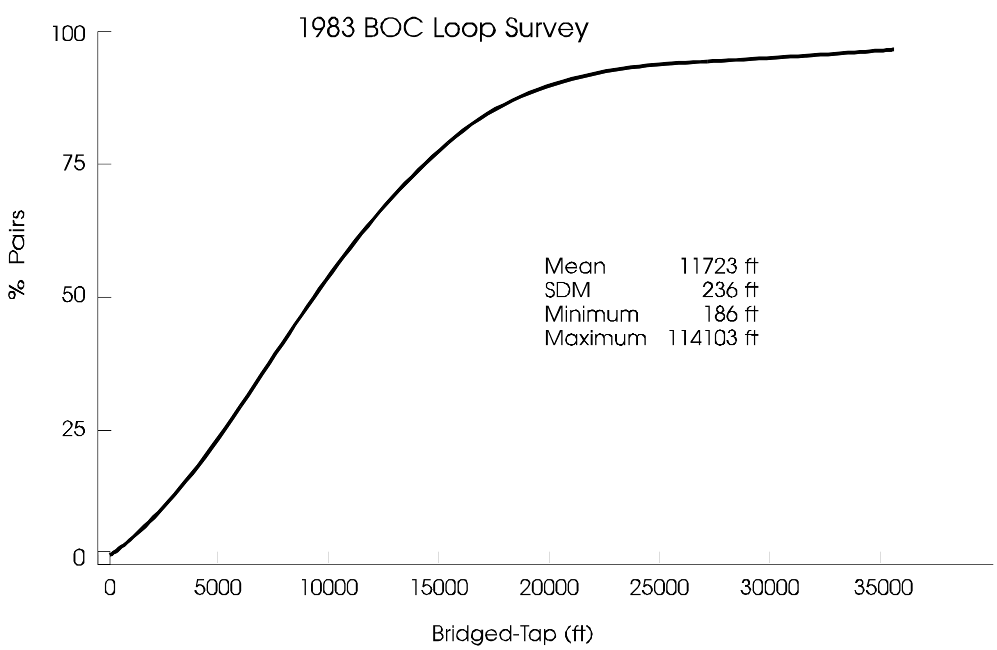


Figure 12-10. Working-Length Distribution Residence Loops

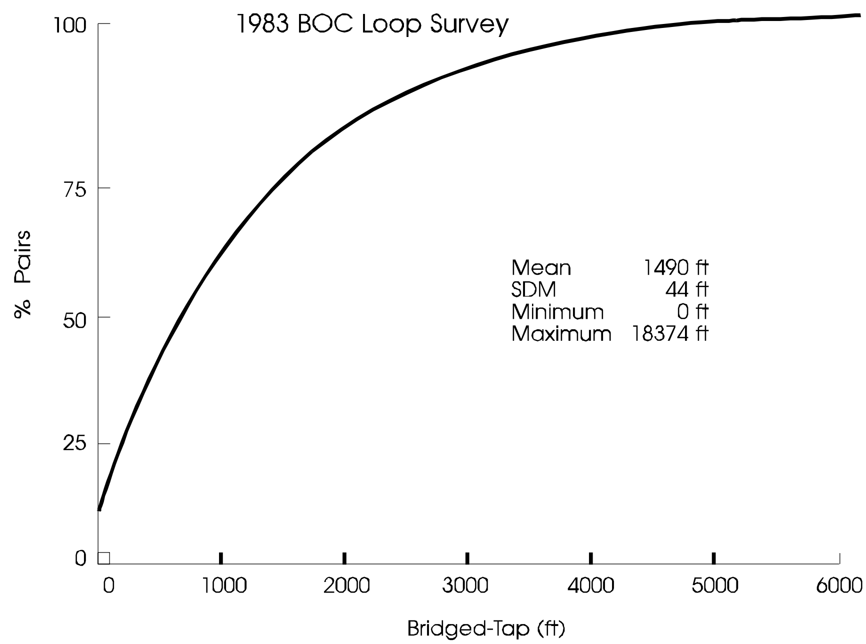


Figure 12-11. Bridged-Tap Length Distribution Residence Loops

12.3.1.3 Business

Table 12-4 contains summary statistics of lengths of sampled business working pairs. Business pairs have an average total length of 9,840 ft, an average working length of 8,816 ft, and an average bridged-tap length of 894 ft. Figures 12-12 through 12-14 present cumulative distribution plots for these statistics. The average working-loop length for a business service is about 30-percent shorter than the average working-loop length for a residence service.

Table 12-4. 1983 Loop Survey — Business Length Statistics

	Minimum ft	Maximum ft	Mean ft	SDM ft
Total Length	250	100,613	9,840	302
Working Length	200	99,569	8,816	296
Total Bridged-Tap	0	11,333	894	47

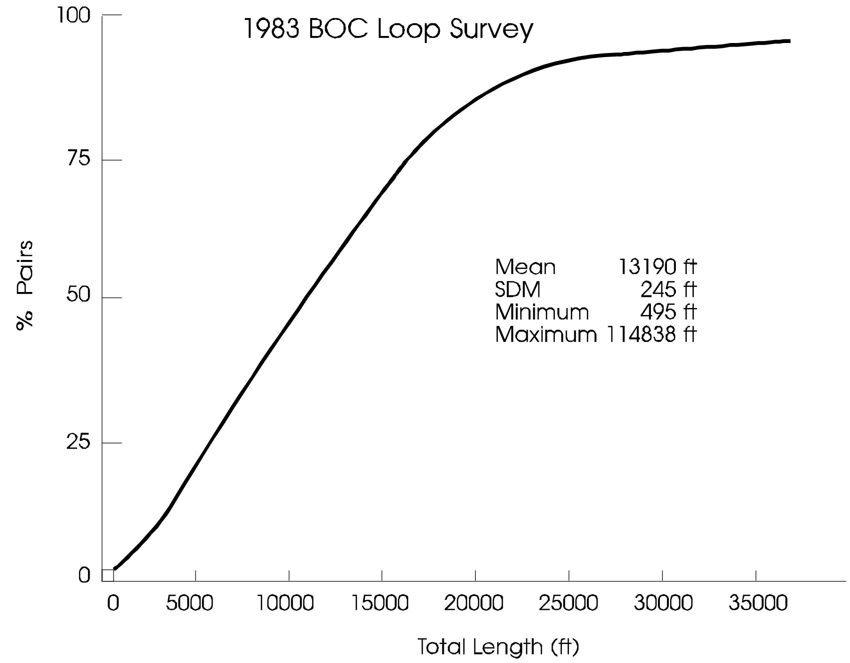


Figure 12-12. Total Length Distribution Business Loops

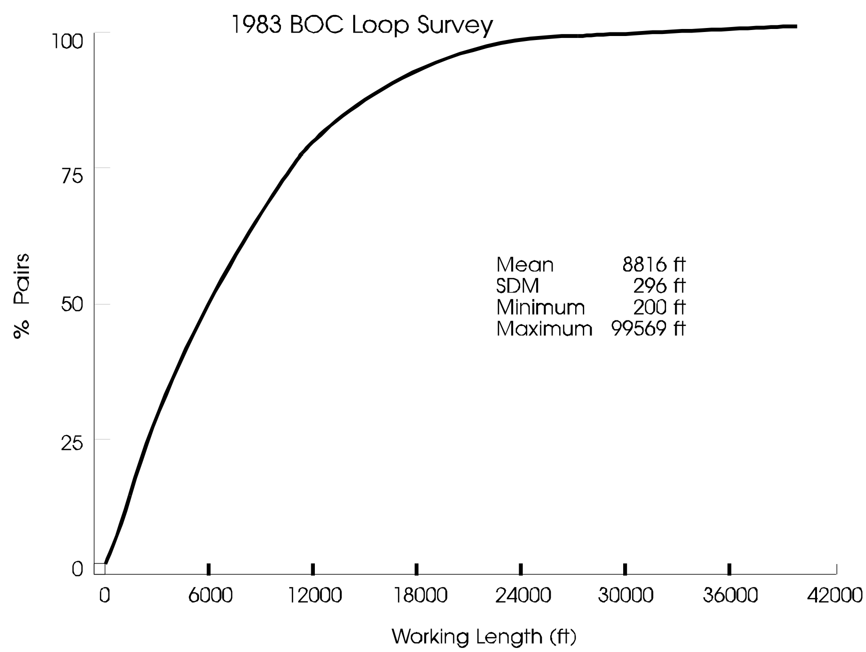


Figure 12-13. Working-Length Distribution Business Loops

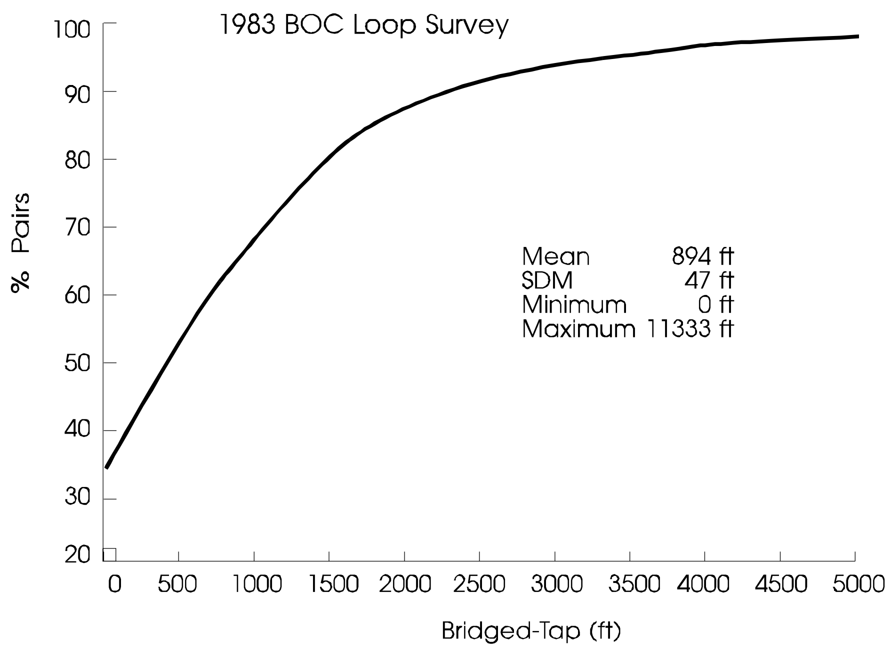


Figure 12-14. Bridged-Tap Length Distribution Business Loops

12.3.2 1987 to 1990 BOC Digital Access Survey

The Digital Access Survey (DAS) consisted of two major parts:

1. A study of wire center characteristics
2. Transmission and physical characteristics of the loop

First, the survey looked at loops served by DLC systems. Second, the survey studied loops served from the potential broadband (PBB) wire centers serving large business customers. Five of the seven existing BOCs participated in the DAS study.

12.3.2.1 Digital Loop Carrier Study

A total of 686 DLC subscriber loops were sampled in the five participating regions. These loops are served from 126 wire centers. The primary conclusions, based upon the 1987 - 1990 data, are:

- In 1987, about 5% of all sampled circuits were provided by DLC systems (growth rate of 20%), corresponding to only 9% of the circuits several years later (i.e., by the end of 1991). These results illustrate the large magnitude of the embedded wire center and loop plant base, such that a considerable time is required before a significant penetration may be achieved in any conversion effort.
- A considerable amount of optical fiber had already been placed into the feeder portion of the DLC plant, corresponding to approximately one-quarter of all

DLC loops. In contrast, there was no evidence of fiber in the distribution plant (see Section 12.12.1, Fiber-in-the-Loop). In addition, a large fraction of non-working fiber is terminated in the wire centers. This available fiber is an indication of a well-planned approach to serve future DLC and/or broadband services.

- Integrated DLC (Section 12.7) represented more than one-quarter of the DLC loops, eliminating the Central Office Terminal (COT). This corresponds to a significant cost savings and improved positioning for providing future digital services.
- More than two-thirds of the DLC loops meet CSA guidelines (Section 12.1). This indicates that much of the loop is able to provide digital services through the use of ISDN, High Bit-Rate Digital Subscriber Lines (HDSL), Asymmetric Digital Subscriber Line (ADSL), and other new loop technologies (see later sections). A large percentage (42%) of the DLC loops contain 22-gauge copper in the distribution portion. Since the CSA guidelines are developed around 24- and 26-gauge cable, which restricts the CSA to 9 kft and 12 kft, respectively, the large use of 22-gauge cable may allow the extension of the guidelines beyond the presently recommended distances.
- Cable sheath age results indicate that the vast majority (98%) of the in-place copper serving DLC loops had not yet been in place sufficiently long to be fully depreciated. Over two-thirds had been installed in the preceding 15 years.
- Cable sheath sizes less than 100 pairs dominate the loop feeder plant beyond 6,000 ft. Thus, the recommended separation of the transmit and receive pairs of the T1 may not be possible. Since such separation is not an issue for HDSL technology, the latter represents a cost-effective alternative for metallic feeder lines to the Remote Terminal (RT).

Some pertinent statistics derived from the data for the DLC wire centers and loop plant are:

- More than two-thirds (67.3%) of the loops are compatible with CSA guidelines. The main reason for incompatibility of the balance is excessive bridged-tap.
- The average working length of the DLC loop plant is 35,238 ft, with a COT to RT length of 29,746 ft, RT to FDI of 1,283 ft (almost one-third of the sampled loops have the RT co-located with the FDI), and a distribution length of 4,209 ft. The average service wire (drop) length for DLC loops is 154 ft, well within present FITL (Fiber To The Curb [FTTC]) requirements (Section 12.12), based upon 500 ft maximum. Indeed, over 90% of all service wires lengths (aerial and buried) are less than 218 ft.
- Approximately one-quarter (24.8%) of all DLC loops were served by fiber feeder, carrying transmission rates ranging from 6 Mbps to 560 Mbps. The large majority (approximately two-thirds, or 67.4%) are at 45 Mbps.
- Twenty seven percent of all the DLC loops were integrated directly into the switch.

- More than one-tenth (11.5%) of the loops are loaded in the distribution portion, and are therefore restricted to voiceband services. Bridged-taps are found on 56% of the distribution portions.
- Almost three-quarters (73.3%) of DLC lines serve residential subscribers.
- The loop plant distribution structure of DLC loops consists of one-third aerial (36.8%), half buried (50.7%), and one-eighth (12.5%) underground plant.

12.3.2.2 Potential Broadband (PBB) Study

A total of 559 loops serving large business locations were sampled in the same 5 participating regions, selected from 101 wire centers. The primary conclusions are:

- The feeder plant is only in an early positioning stage for providing future broadband services; i.e., optical fiber was beginning to be terminated in potential broadband wire centers, but did not yet provide direct service to a significant number of large customer sites. In addition, half of the PBB wire centers had no digital switching machines. However, conversion to digital switching is a major objective and has been progressing well.
- The PBB serving area is well positioned to take advantage of the ISDN DSL and other high bit-rate technologies; i.e., spare copper pairs are available at the wire centers and major customer sites. Approximately half of the loops serving large business sites meet CSA guidelines and will support DSL rates. The copper is relatively new and will be available for many years to support advanced copper-based technologies.
- Those loops not consistent with CSA guidelines are compromised by the presence of load coils and bridged-taps. Most of the loading and bridged-taps are located in the feeder portions because relatively few of these business loops have a distribution section.

Some pertinent statistics derived from the PBB data are:

- Approximately one-eighth (13%) of all PBB wire centers have a high potential to provide future broadband services. These wire centers serve more than 43% of all working circuits in the five regions.
- More than three-quarters (76.6%) of the loops serving large business sites terminate the feeder directly at the customer’s premises; i.e., there is no distribution portion.
- The average working length from the CO to the customer’s building entrance facility, for a large business located within a PBB serving area, is 13,092 ft, including an average feeder section of 12,634 ft and distribution section of 458 ft. Excluding those loops without any distribution segment (zero length), the average distribution section is 2,057 ft.
- Approximately 8% of the loops were served by fiber feeder. Thus, 92% were served entirely by metallic facilities at the time of the survey.

- Twelve percent of the loops were served by DLC systems (fiber or copper feeder).
- A large majority of the loops to large business customers are in underground conduit, with limited spare duct capacity.
- Only 3% of the large business sites are served by optical fiber, with an average cable size of 12 fibers. Considerably more fiber is available in the feeder plant but is not directly connected to the customer.
- The loop plant serving large business locations is comprised of 10% aerial, 6% buried, and 84% underground plant.
- The PBB loop plant contains approximately 22% of 22-gauge, 40% of 24-gauge, and 38% of 26-gauge copper cable. Negligible 19-gauge is present.

12.3.3 1993-1998 Loop Plant Analysis

The FCC requires LECs that are subject to price cap regulations to report service quality and network infrastructure information. This information is collected in the ARMIS database. All information reported by LECs can be viewed by logging on to www.fcc.gov/ccb/armis/welcome.html and following the instructions. The loop plant information detailed below has been obtained from ARMIS Report 43-07 filings for the years 1993-1998.

For the typical LEC, a large portion (50% - 70%) of new line growth is served by DLC. In the period from 1993 to 1998, DLC systems accounted for 2/3 of all new lines. Figure 12-15 shows the growth in access lines served by baseband copper (copper wires from central office to customer premises), copper-fed DLC, and fiber-fed DLC. Baseband copper and copper DLC deployment is slowly increasing. Most growth is in fiber-fed DLC deployment. In 1998 there were approximately 182.5M working access lines and 97M spare loop circuits. Figure 12-16 indicates the aggregate (for all LECs) growth rate trends for baseband copper and DLC access lines. The growth rate of baseband copper is decreasing in the loop plant, as might be expected, because DLC systems are a more economical alternative to copper. In fact, several LECs reported negative growth in baseband copper access lines. Some LECs have been aggressively deploying DLC systems to the extent that more than 30% of their access lines are currently served over DLC systems.

Figure 12-17 compares the working access line growth for copper-fed DLC with fiber-fed DLC in the period 1993-1998. Copper-fed DLC deployment is relatively flat, while fiber-fed DLC deployment is steadily increasing. Over this period, the percentage of working access lines served by DLC has more than doubled from 12% to 24.5%.

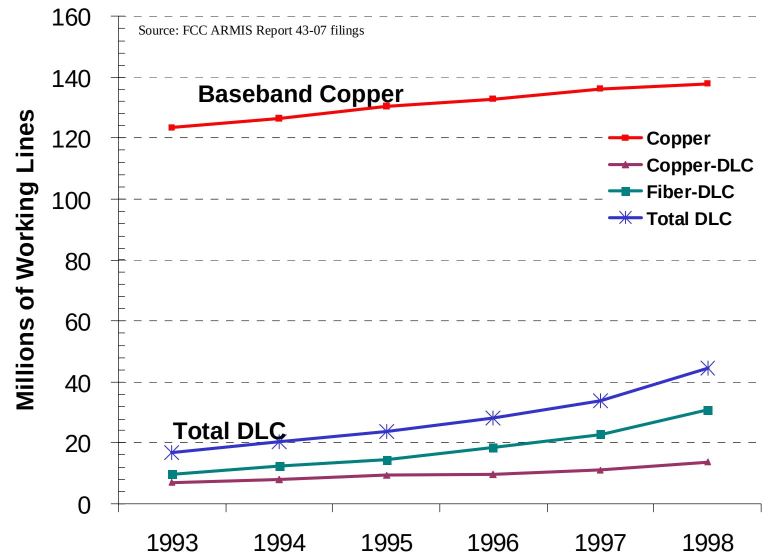


Figure 12-15. Growth in Working Lines

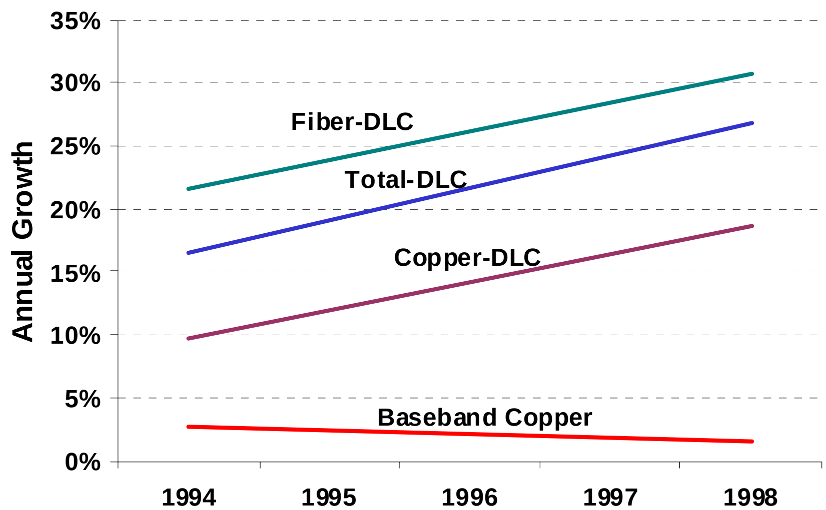


Figure 12-16. Access Line Growth Rate Trends

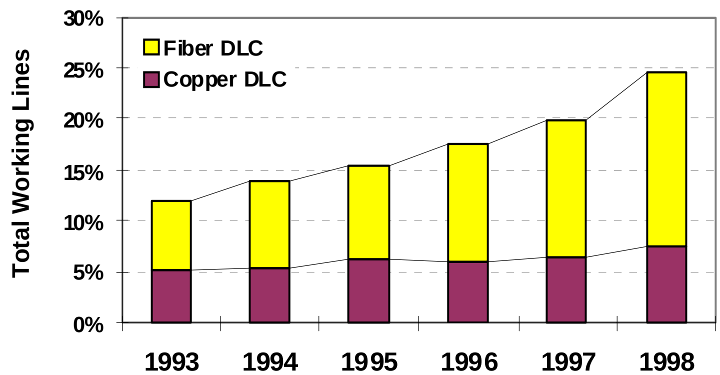


Figure 12-17. Working Lines Served By DLC (Local Exchange Carrier Average)

12.4 Voice-Frequency Channel Terminating Equipment

Voice-frequency terminating equipment is available to meet the wide range of transmission (Section 7), signaling (Section 6), test requirements for Message Telephone Services (MTS), and special access over metallic facilities. Terminal equipment at the end office may provide the necessary interface between 2-wire and 4-wire facilities and can provide transmission only, signaling only, or both, in single units. At present, when central office equipment is not sufficient or adequate, Network Channel Terminating Equipment (NCTE) is needed at the customer location for terminating special-access lines or trunks.

Since there are a variety of serving arrangements, a different NCTE unit is usually needed for each. However, some units are multifunctional and can be used for more than one serving arrangement. Serving arrangements include 2-wire, 4-wire, and 6-wire arrangements; loop signaling, duplex (DX) and single-frequency (SF) signaling; impedance compensation; and 4-wire loopback arrangements.

12.5 Analog Loop Carrier

Analog carrier systems, both single channel and multichannel, have been available for loop applications for about 30 years. The single-channel systems provide an additional channel (called an “add-on” channel) by using a frequency spectrum above the voice-frequency band. These systems are usually used as an interior arrangement in congested areas to defer new cable or drop installations.

The multichannel systems generally provide four to eight channels on a single cable pair. Unlike the single-channel systems, no voice frequency channel is provided. Multichannel analog loop-carrier systems provide either a lumped (or “concentrated”) remote terminal where all customer connections are made, or a distributed remote terminal arrangement where one or more customer connections are made in several locations on the same system. The multichannel systems are used in low-growth areas, typically on long loops.

Some analog carrier systems may be affected by ISDN BRA DSL (Section 12.9) and other digital services. Spectrum management (see Section 7) concerns have caused some Telcordia client companies to stop deploying these systems. Furthermore, many analog systems are being removed in areas where ISDN or new digital services are planned or forecast. Universal Digital Channel (UDC) systems are being deployed to avoid spectrum incompatibility (see Section 12.10).

12.6 Universal Digital Loop Carrier

Universal Digital Loop Carrier (UDLC) systems were introduced in the early 1970s as an economical alternative to metallic facilities for long feeder routes (see Figure 12-18). As the cost of UDLC systems decreased and their service capabilities increased, they began to be used in suburban and urban areas with greater frequency. The decreased cost permitted the systems to become an economic substitute for cable at increasingly shorter loop lengths, and the improved service capabilities opened new applications for UDLC systems.

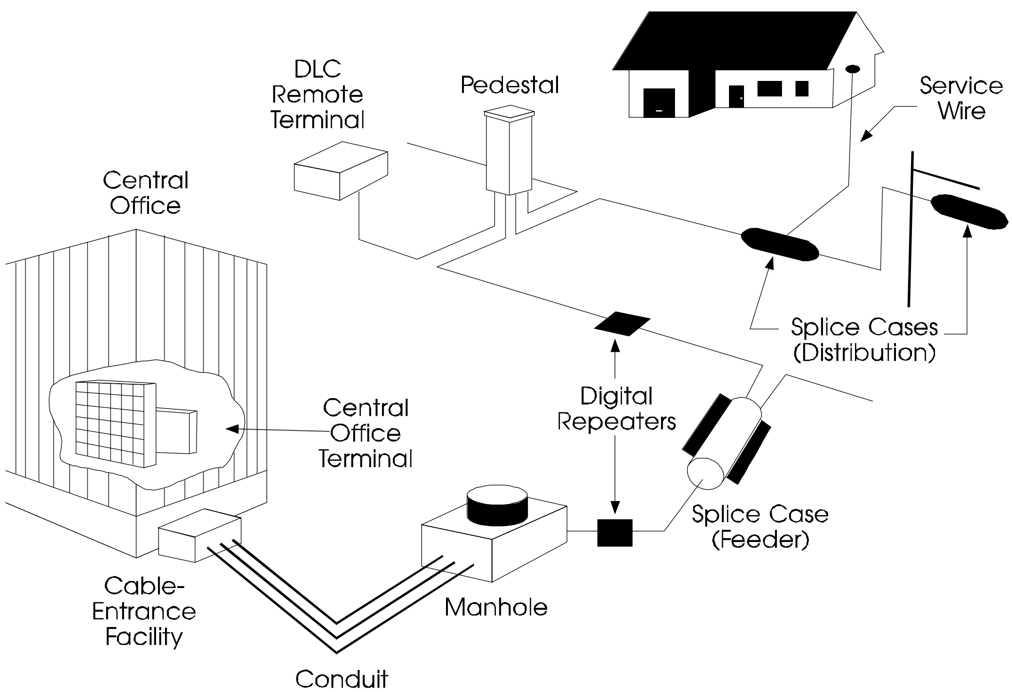


Figure 12-18. Distribution Network — Digital Loop Carrier

UDLC systems consist of a Central Office Terminal (COT) located near the switching system, a Remote Terminal (RT) located near the customer to be served, and a digital transmission facility connecting the COT to the RT (see Figure 12-19). TR-NWT-000057, *Functional Criteria for Digital Loop Carrier Systems*, treats UDLC systems as complete systems consisting of a COT and an RT. This document describes the interfaces between the COT and the local switching system, and between the RT and the customer, but it does not specify the interface between the COT and the RT. Individual communications circuits (such as POTS and Foreign Exchange [FX]) are accepted as separate inputs at the COT (RT), time-division multiplexed by the UDLC system, and reproduced at the RT (COT). There is an analog-to-digital (A/D) conversion of analog inputs to the UDLC, and these signals, which are carried digitally within the UDLC, undergo a digital-to-analog (D/A) conversion when output at the COT or RT. In addition, some new UDLC systems offer optional features, such as high-speed, digitally multiplexed output ports and DS0 digital cross-connect functionality.

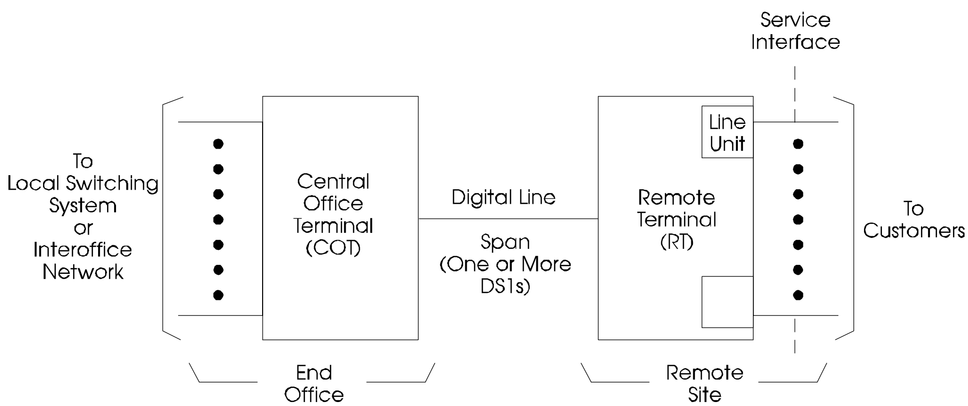


Figure 12-19. Universal Digital Loop Carrier Configuration

The digital transmission facility used by a UDLC system may be repeatered metallic cable pairs, or optical fibers. Either or both of the facilities are combined with digital multiplexers or other appropriate media. TR-NWT-000057 requirements assume the use of a digital facility operating at a DS1 rate.

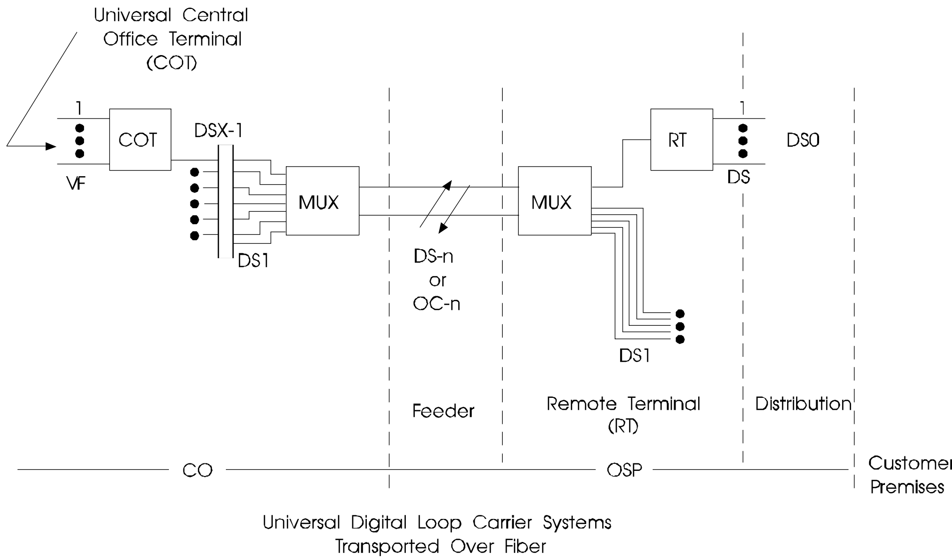
UDLC systems have extensive operations features allowing single-ended maintenance from either the COT or the RT. Among the features are automatic protection switching for digital facility failures, remote alarm capabilities, and remote testing of digital facilities and the distribution plant. In addition to the digital facility, COT, and the RT, a UDLC system may rely on other elements to permit maintenance and overall operation (see Table 12-5).

Table 12-5. DLC System-Related Elements

DLC System-Related Elements
Feeder Plant
Remote test units Remote terminal Digital line (T-lines or optical fibers) Structure (poles or conduit) Manholes, apparatus cases, repeaters, splice cases Lightguide Interconnection Terminal (LIT) Multiplexers Remote terminal housings (controlled environmental vault/huts/cabinets) Land for remote terminal housings Environmental alarms
Central Office
Main Distributing Frame (MDF) Interior cabling Digital Signal Cross-connect (DSX) Central Office Terminal (COT) Lightguide Interconnection Equipment (LIE) Multiplexers Office Repeaters and Bays (ORB) Line interface modules Central office support systems (power, space, operations interface, etc.)

UDLC circuit maintenance is generally accomplished by the use of the Pair-Gain Test Controller (PGTC) and a bypass pair to provide metallic test access to the distribution pairs. The PGTC interface is described in TR-TSY-000465, *Interface Between Loop Carrier Systems and Loop Testing Systems*. When the distance is too large for the bypass pair to provide meaningful readings, a Remote Test Unit (RTU) is installed within the remote terminal site to allow metallic test access. In addition, RTUs are also installed in remote terminal sites where their use can be cost-justified.

Large multiple remote terminal sites have permitted the use of higher-rate digital transmission facilities (such as optical fibers and multiplexers) between COTs and remote terminals (see Figure 12-20). In some cases, optical fibers are the only transmission media available between the central office and the multiple remote terminal site.



Legend:

DS-n	=	Digital Signal -n
DSX	=	Digital Signal Cross-Connect
MUX	=	Multiplexer
OC-n	=	Optical Carrier -n
OSP	=	Outside Plant
RT	=	Remote Terminal
VF	=	Voice Frequency

Figure 12-20. UDLC Over Fiber

The increasing use of large multiple-system remote terminal sites and the increased ability of UDLC systems to provide services in addition to conventional Message Telephone Service (MTS or POTS) call for a more systematic approach to deploying UDLC systems. A systematic UDLC deployment would allow cost reduction associated with custom loop conditioning often required for digital data services and voice-frequency special-service circuits, and the ability to offer new access services. UDLC systems can support a wide range of different services. Single-party and multiparty POTS service still represents the majority of circuits being transported over UDLC; however, a large number of coin services, voice-frequency special services, and other circuits are also supported via UDLC. Table 12-6 presents a list of some available service applications.

Table 12-6. UDLC Services

UDLC Services
Message telephone service (POTS)
Coin
Multiparty
Centrex
Private Branch Exchange - Central Office (PBX-CO) trunks
Local WATS
Foreign exchange (FX)
Voice-grade private line
Digital Data Service (DDS) (≤ 64 kbps)
ISDN basic rate access (144 kbps)

Large remote terminals providing hundreds of circuits allow more automated capabilities such as remote service provisioning and remote equipment inventory. Remote terminal-based, digital cross-connect functions, and digital test access become cost effective when large remote terminals are used. In general, operations functions (such as monitoring, testing, provisioning, and taking inventory) become extremely cost effective when integrated within a UDLC system.

12.7 Integrated Digital Loop Carrier

DLC systems discussed in Section 12.6 can be used with any switching system because the interface presented to the switching system by a circuit carried within the DLC system is the same as if the circuit were carried on a metallic pair of wires. The introduction of digital switching systems has made it possible for the DLC COT to be eliminated by integrating many of the COT functions into the switching system. The A/D and D/A conversions that are done in a DLC COT for analog signals are not required at the switching system interface; instead, the signals are switched in their digital form, and conversions are done elsewhere in the telephone network, when needed.

In an Integrated Digital Loop Carrier (IDLC) system, the Remote Digital Terminal (RDT) has a direct interface to the digital switching system. The switching system provides all the functionality associated with terminating the digital facilities. These digital facilities may be a DS1 or higher-rate digital facility on a metallic or optical fiber transmission medium. The switching system also provides capabilities for an IDLC system to interface external systems or equipment for surveillance, provisioning, and maintenance operations.

The interface between the switching system and the RDT may be proprietary; that is, the switching system and the RDT are provided by the same supplier, or a switching system supplier and an RDT supplier have reached an agreement as to the interface. At divestiture in 1984, there was a large embedded base of SLC®-96 IDLC systems. Telcordia has described the SLC-96 interface in TR-TSY-000008, *Digital Interface Between the SLC®-96 Digital Loop Carrier System and a Local Digital Switch*. Telcordia has also defined the requirements for an IDLC system and a generic IDLC interface in GR-303-CORE, *Integrated Digital Loop Carrier System Generic Requirements, Objectives, and Interface*. Figure 12-21 depicts the three types of IDLC interfaces: TR-TSY-000008, GR-303, and proprietary. The TR-TSY-000008 and GR-303 generic interfaces are briefly described in Sections 12.7.1 and 12.7.2.

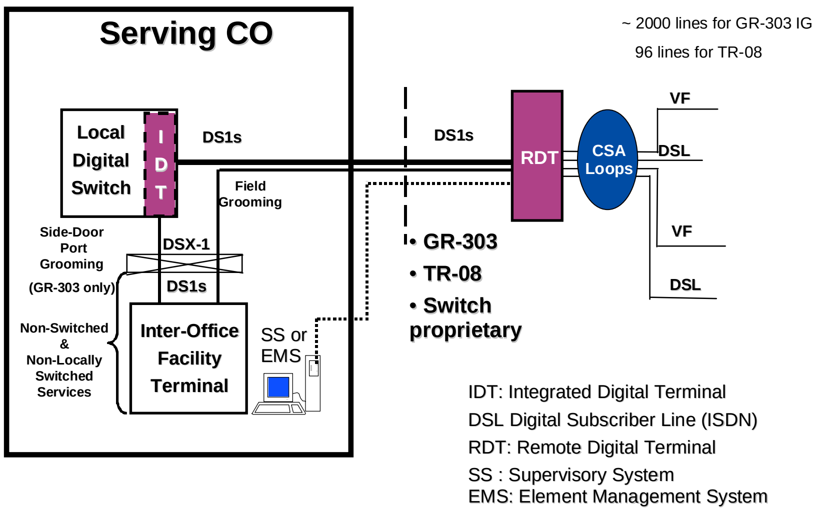


Figure 12-21. IDLC Interfaces (TR-08, GR-303, Proprietary)

12.7.1 TR-TSY-000008 Interface

TR-TSY-000008 describes the requirements necessary for a Local Digital Switching (LDS) system to connect to a SLC-96 RDT across a digital interface at the T1 rate of 1.544 Mbps. However, TR-TSY-000008 is now recognized as a generic interface that provides a multivendor environment with mix-and-match capabilities between switching systems and DLC systems. This technical reference also describes the interface requirements that will allow an RDT to mimic the SLC-96 RDT in order to interface an LDS that provides an interface meeting the requirements of TR-TSY-000008. However, TR-TSY-000008 does not describe system requirements or requirements for the RDT-to-customer interface.

The digital interface between the LDS and RDT is specified at the DSX-1 level. The DS1s from the RDT pass through an Office Repeater Bay (ORB) and are terminated on a DSX-1 frame. The DS1s are then cross-connected at the DSX-1 frame to the LDS. The interface supports from two to four DS1s per RDT without facility

Automatic Protection Switching (APS), and from three to five DS1s with facility APS. The LDS can interface the RDT in MODE I, no concentration; MODE II, 48 circuits concentrated on 24 DS1 time-slots; and MODE III, 24 special-service circuits on 24 DS1 time-slots.

The DS1s use a format in which 12 DS1 frames are grouped together to form a superframe. The signaling and supervision information is carried between the RDT and LDS using a method called *robbed* (stolen) bit signaling. The least-significant digit in a circuit's DS1 time-slot is robbed every sixth (A bit) and twelfth (B bit) frame to generate a per-circuit signaling channel. By toggling the A and B bits, nine signaling codes can be defined from the two bits. This per-circuit signaling channel is used to carry signaling and supervision information, such as on-hook, off-hook, ringing, and coin-control signals between the LDS and RDT. The channel also carries a channel-test initiate signal for those channels that can be tested using the PGTC discussed in the DLC section.

The superframe framing bits are split between a DS1 framing sequence and a signaling frame on two of the DS1s between the LDS and RDT. Of the 36 signaling frame bits available every 9 ms, 24 are used to derive four operations channels, while the remaining 12 are used to resynchronize the four operations channels. On one of the DS1s, a concentrator channel, maintenance channel, alarm channel, and protection line switch channel are derived. If the RDT needs a second concentrator channel for MODE II operation, the second DS1 will have a concentrator channel; otherwise, there are no operations channels on the second DS1. The concentrator channel is used to control activity requests and time-slot assignments for a MODE II RDT. The maintenance channel is used to control channel and distribution pair (drop) testing. The alarm channel is used to exchange alarm data between the LDS and RDT. The protection line switch channel is used to control facility APS when a system is equipped with a protection DS1.

The interface supports an RDT that terminates up to 96 subscriber lines. The RDT can provide single-party, multiparty, coin, and other locally switched circuits. If non-locally switched circuits are provided by the RDT, the circuits must be groomed in the field onto a DS1 that does not terminate on the LDS, or the LDS must provide the capability to bring the circuits out of the switch to an interoffice facility. As a third option, some switching systems may allow the *nail-up* of circuit in capable switches.

The TR-TSY-000008 generic interface has the following limitations which are overcome when using the GR-303-CORE generic interface specification:

- Inefficient support of COIN and Special Services circuits
- No ISDN support (must use 3DS0 paths to a COT)
- Limited support for remote operations (no provisioning, limited alarm reporting, limited channel testing and maintenance).

12.7.2 GR-303-CORE Interface

In September 1986, Telcordia first published TR-TSY-000303, *Integrated Digital Loop Carrier System Generic Requirements, Objectives, and Interface*. All cumulative changes and additions to IDLC requirements, as well as an upgrade to the GR format, are provided in GR-303-CORE, Issue 3, December 1999. GR-303-CORE describes the overall generic requirements for an IDLC system as well as a generic IDLC interface between an LDS and an RDT. The IDLC system consists of an Integrated Digital Terminal (IDT) in the LDS, an RDT that terminates on the IDT (see Figure 12-21), and 2 to 28 DS1 facilities connecting the IDT and RDT. The IDT is a logic device in the LDS that consists of all the resources of an LDS that are needed to terminate one RDT. The DS1s between the LDS and RDT use Extended Superframe Format (ESF).

The key feature of GR-303-CORE is the generic IDLC interface between the LDS and RDT. The generic IDLC interface allows the LECs to mix and match LDSs and RDTs from different suppliers. The generic IDLC interface uses a DS0 as an Embedded Operations Channel (EOC) between the RDT and LDS. The LDS provides a network-layer or application-layer mediation function that allows operating systems and RDTs to communicate with each other over the EOC. The messages that cross the EOC are based on the Common-Management Information Services (CMIS), Remote Operations Service (ROS), and Abstract Syntax Notation One (ASN.1) defined by the International Standards Organization (ISO) and the International Telecommunication Union—Telecommunication Standardization Sector (ITU-T).[4] The management information model for DS1-based IDLC systems is described in GR-303-IMD, published in December 1998. The Link Access Procedure on the D-channel (LAPD) is used as the data-link layer protocol on the EOC.

An IDLC RDT can support a rich set of operations messages over the EOC. This allows the RDT to provide capabilities such as a digital cross-connect and maintenance functions that are managed over the EOC.

The generic IDLC interface also supports two different call-processing techniques. The first is called *hybrid signaling*. In hybrid signaling, ABCD codes are used for call supervision (for example, on-/off-hook detection) while a time-slot is assigned to a line unit. Per-call time-slot assignment is accomplished over a 64-kbps Time-slot Management Channel (TMC) that carries messages between the LDS and the RDT. These messages are used to make and break time-slot assignments between line units and DS0s on a per-call basis.[5] The second call-processing technique is *out-of-band signaling*. It consists solely of a 64-kbps channel, the Common Signaling Channel (CSC). The CSC carries messages for making time-slot assignments and for call supervision. RDTs that use a CSC may use it only for call supervision, not to perform time-slot assignments on a per-call basis. The CSC technique has not been

4. Formerly the International Telegraph and Telephone Consultative Committee (CCITT).

5. RDTs that do not have a per-call time-slot assignment capability do not require a TMC since no time-slot assignment messages need to be exchanged between the LDS and RDT.

implemented by suppliers. All current LDS-RDT configurations utilize the hybrid signaling/TMC method.

Both the TMC and CSC employ the LAPD protocol that is used on ISDN D-channels. The TMC and CSC messages are based on the CCITT Q.931 standard, *ISDN-User Network Interface Layer 3 Specification*, and are largely consistent with the ISDN call control requirements in GR-268-CORE, *ISDN Access Call Control Switching and Signaling Requirements*. In this way, technology developed to support ISDN basic and primary rate access can be adapted for call processing across the generic IDLC interface.

To enable connection with different RDTs serving a wide range of applications, the LDS must accommodate both call-processing techniques, but not simultaneously for any one RDT.

The generic IDLC interface supports the transport of ISDN BRA (see Section 12.9) lines using a method called “4:1 time-division multiplexing.” For ISDN DSLs that terminate on the RDT, the B-channels are transported in DS0s while the D-channel of the DSL is time-division multiplexed with up to 3 D-channels from other DSLs for transport to the LDS. This method provides an economical transport mechanism for ISDN BRA lines. The RDT will also translate messages received over the EOC into DSL-embedded operations channel messages for ISDN DSLs.

GR-303-CORE also describes a generic IDLC interface based on the Synchronous Optical Network (SONET). The major changes occur at the physical layer where the physical layer is provided as a byte synchronous SONET signal with VT1.5 transport used instead of DS1-based transport. All per-channel signaling is done out-of-band using the SONET overhead. Other than the changes in the performance monitoring requirements, DS1 and SONET-based IDLC systems must meet the same requirements.

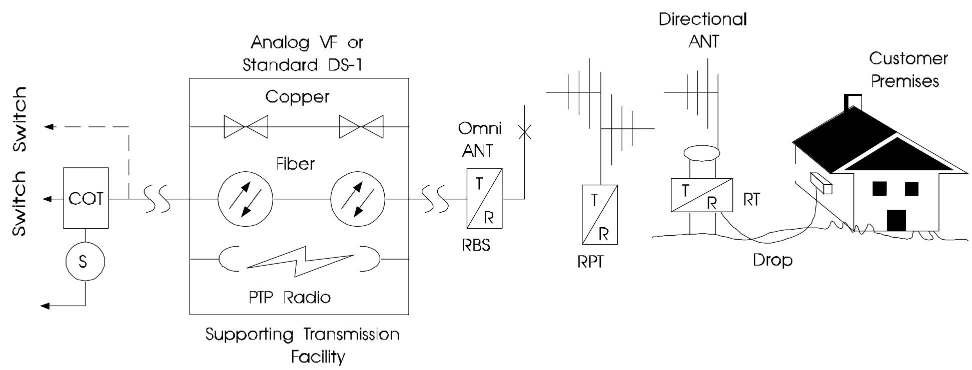
12.8 Basic Exchange Radio System

In providing telecommunications services in rural areas with low population density, both the initial capital cost and the ongoing maintenance cost can be very high if long cables or long open wires are used to reach the scattered subscribers in very remote locations. Basic Exchange Radio (BEXR) systems are economically attractive in providing rural telecommunications services because of recent advances in micro-electronics, digital radio, and voice-coding technologies. Both capital and maintenance savings are possible.

A digital BEXR system is a point-to-multipoint wireless DLC system. It is used in subscriber loops to provide economical basic telecommunications services to fixed subscriber locations. The frequency plans for BEXR systems in the United States are the same as those for land-mobile radio systems in 150-MHz and 450-MHz bands. However, in the 800-MHz frequency band, only a subset of the channels for land-mobile radio systems is assigned for BEXR. The channel spacing is 25 kHz in 450-MHz and 800-MHz bands and is 30 kHz in 150-MHz bands. The same frequency plan is shared by land-mobile radio and BEXR on a co-primary basis as authorized by the

FCC in December 1987. The land-mobile radio is used primarily in or near metropolitan areas, whereas BEXR is used reasonably far away from metropolitan areas. The geographic separation between these two different applications allows sharing of the same frequency bands.

Figure 12-22 shows a functional block diagram of the digital BEXR system. The basic functional modules of the digital BEXR system are the COT that interfaces with the local exchange switch, the Radio Base Station (RBS) acting with the COT as the multiplexer and the main radio distribution point, and the RT relating directly between the customer line and RBS. The COT is usually located near the local exchange switch. The RBS is usually located either with the COT or remotely at a site with high elevation to optimize the point-to-multipoint radio transmissions to cover many scattered subscribers. The RT is located near the subscriber location. The transmission facilities between the COT and the RBS can be voice-frequency cable pairs or standard digital transmission facilities such as T1-carrier, digital microwave radio, or optical fiber systems. In some situations, a radio repeater may be used if there is no direct line-of-sight between an RT and the RBS.



Legend:

ANT	=	Antenna (type varies)
COT	=	Central Office Terminal
Customer premises	=	mounting arrangement
Drop	=	LEC standard copper facility
PTP Radio	=	any point-to-point radio external to the system
RBS	=	Radio Base Station
RPT	=	Radio Repeater
RT	=	Remote Terminal
S	=	Standard operations system interface
SDP	=	Standard Demarcation Point
Switch	=	any local exchange office
T/R	=	Transmit/Receive (connections vary)

Figure 12-22. Digital BEXR System

Each RT receives and transmits on a pair of Radio Frequency (RF) channels in both Frequency-Division Multiple Access (FDMA) and Time-Division Multiplexing (TDM) or Time-Division Multiple Access (TDMA) modes.

For example, in the 450-MHz band, the 650 kHz of total allocated frequency bandwidth for one direction of transmission is divided into 26 RF channels with 25-kHz channel separation using FDMA. Digital signals from multiple subscribers may be multiplexed on each 25-kHz RF channel by either TDM or TDMA. Voice-coding techniques may be used to compress the bit rate of the digitized voice signal of an individual subscriber. The RBS concentrates and compresses the digital baseband voice signals from the COT, multiplexes them into channel groups, and broadcasts these multiplexed channels to the subscriber community. The radio signal is modulated with an optimum digital modulation scheme as determined by the class and quality of service desired. Additionally, the modulation levels may vary from subscriber to subscriber as necessary to improve system gain and to overcome poor propagation conditions encountered on certain difficult radio paths. By using a Demand Assignment Multiple Access technique, each RT can access any of the 26 RF channels in the 450-MHz band, and any of the individual voice circuits multiplexed within an RF channel. The total number of subscribers that can be served from a particular system depends on the quality of service desired and the modulation technique employed. For example, the maximum number of subscribers that can be served by an available BEXR product is 570 in the 450-MHz frequency band alone. If 150-MHz and 800-MHz bands are also available at the same serving area, the maximum number of BEXR subscribers can be considerably larger. The number of BEXR channel pairs in the 150-MHz, 450-MHz, and 800-MHz bands is 18, 26, and 50, respectively.

The RBS normally employs an omni-directional antenna. The RT usually uses a Yagi antenna with about 10-dB gain. A system gain of 130 dB or more is employed to ensure adequate and reliable coverage for this type of system. Additionally, techniques such as Automatic Power Control (APC) may be used to increase system gain and to equalize the RBS-received power levels from various RTs. The typical coverage area of an RBS is about 60-kilometer radius under good propagation conditions. An ITU handbook titled *Rural Telecommunications*, CCIR[6] Report 380-2 (MOD F), and CCIR Report 1057 (MOD F) provide additional information on point-to-multipoint TDMA digital radio systems for rural telecommunications services.

The BEXR systems also contain many features to meet the functional requirements of DLC systems such as signaling, supervision, and maintenance.

In addition to rural telecommunications services, BEXR systems are also being used for the following applications:

- To provide services to areas with temporary or seasonal needs or with uncertain future growth. Examples are oil exploration, construction sites, mining sites, conventions, visiting ships, etc.
- To provide emergency telephone services during a disaster. Examples are hurricane, earthquake, crash site of a large commercial airplane, etc.
- To bring telephone services to off-shore islands or over swamp areas

6. The International Radio Consultative Committee (CCIR) is now called the International Telecommunication Union—Radiocommunication Sector (ITU-R).

- To upgrade services for subscribers from multiparty line to single-party service
- To defer the high construction cost of a new cable route to meet a small amount of new demand; i.e., instances where growth has resulted in the exhaustion of current facilities and expensive, new cable construction may be necessary to meet a small amount of new demand.

With the addition of a digital encryption feature, the BEXR system can also be used as an overlay backup secure communications system. A very recent technical breakthrough, and the encouragement of the FCC to utilize the radio spectrum to hasten competition in the exchange area, have led to aggressive explorations by potential carriers of the use of higher frequency bands (e.g., 2-30 GHz for the one-way distribution of wideband and broadband information and for two-way loop access). Currently there are a few in-service systems and a limited number of technology trials focusing largely on interference issues. Applications, market, and technology issues are still under exploration.

12.9 Integrated Services Digital Network

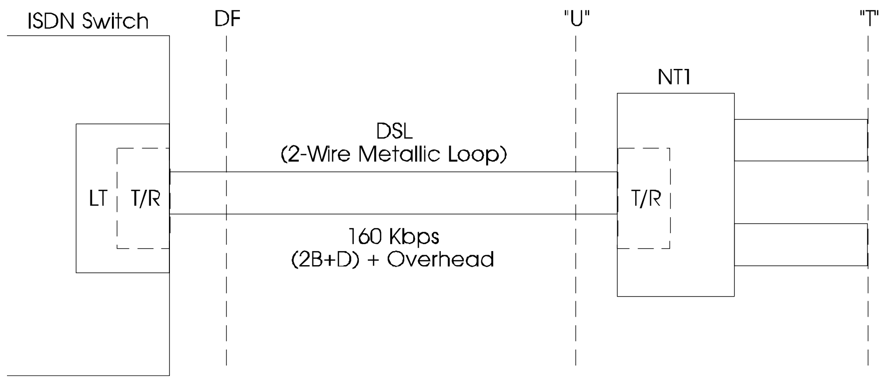
Integrated Service Digital Network (ISDN) is an end-to-end digital network serving voice and nonvoice services. It uses an intelligent signaling network and a small set of user-network interfaces. ISDN will allow the existing telephone (voice-data) network to evolve gradually into an integrated network capable of handling voice, data, video, text, and graphics.

Three ISDN standard interfaces have been identified:

- Basic Rate Access (BRA)
- Primary Rate Access (PRA)
- Broadband access.

12.9.1 Basic Rate Access Interface

The BRA interface uses the Digital Subscriber Line (DSL), as described in TR-NWT-000393, *Generic Requirements for ISDN Basic Access Digital Subscriber Lines*, to deliver 144 kbps of bidirectional customer data, information rate, plus one bidirectional channel of 16 kbps to support provisioning and maintenance, including performance monitoring and framing. This makes the total data rate of 160 kbps in each of the two directions of transmission (see Figure 12-23).



Legend:

DF	=	Distribution Frame
DSL	=	Digital Subscriber Line
LT	=	Line Termination
NT1	=	Network Termination 1
"T"	=	"T" Reference Point (4-wire)
T/R	=	DSL Transceiver
"U"	=	"U" Reference Point (2-wire)
B	=	64 kbps
D	=	16 kbps

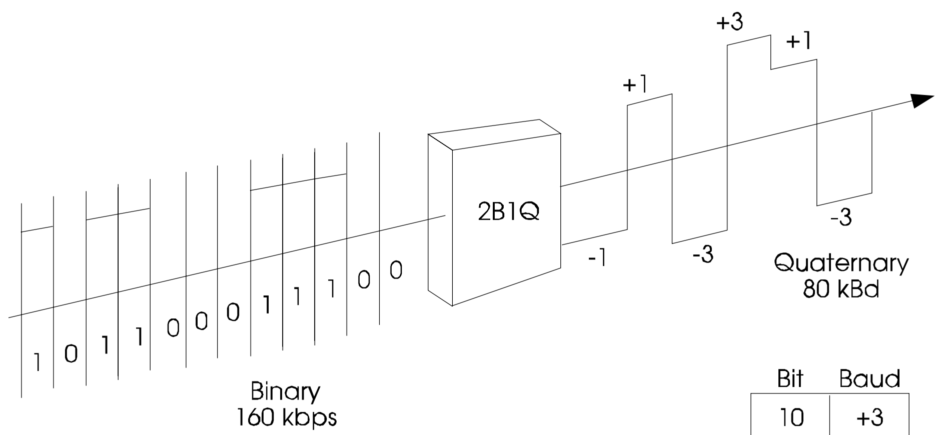
Figure 12-23. ISDN Basic Rate Access Configuration

12.9.1.1 Digital Subscriber Lines

The DSL consists of a master digital transmitter/receiver (transceiver) and a slave digital transceiver, connected by a 2-wire metallic loop. Timing and control information are provided by the master to the slave. The DSL uses the Echo Cancelers with Hybrid (ECH) principle to provide full-duplex signal transmission over a 2-wire nonloaded loop. The echo canceler technique is used to remove echoes of the transmitted signal that have mixed with the received signal. The echoes are reflections of the transmitted signal from discontinuities, such as bridged-taps and gauge changes, or from line impedance mismatches and transformer hybrid leakage. This permits a weakly received signal to be accurately detected and provides the means for avoiding the use of separate pairs of wires for each direction of transmission.

Once the transceivers are powered and joined by a 2-wire loop, they establish communications automatically without field adjustments. These transceivers operate over metallic nonloaded loops originally installed for voice-frequency transmission. These loops do not require plant conditioning or pair selection. They may be aerial, buried, or underground cables with a variety of gauges, pair counts, splices, and bridged-taps. The DSL system is intended to operate on nearly all nonloaded loops 18 kft or less in length and meeting 1300 Ω resistance design rules, based on results of the 1983 loop survey described earlier in this section.

The maximum signal power loss (at a frequency of 40 kHz) is about 42 dB. The DSL uses a 4-level Pulse-Amplitude Modulation (PAM) code without redundancy. This line code is commonly referred to as 2B1Q (2 Binary, 1 Quaternary). Figure 12-24 illustrates the quaternary symbols and the 2B1Q line code. The average power of a 2B1Q transmitted signal is between 13.0 and 14.0 dBm over a frequency band from 0 Hz to 80 kHz, with a nominal peak of the largest pulse being 2.5V. As discussed earlier, the DSL binary information rate is 160 kbps, but the baud rate on the line is 80 kBd ±5 parts per million.



Bit	Baud
10	+3
11	+1
01	-1
00	-3

Figure 12-24. DSL Line Code — 2B1Q

12.9.1.2 Access Architectures

Digital transceivers are embedded in equipment that provides for functions such as powering and network operations support. The master transceiver is in the Line Termination (LT) located in the local switch, and the slave transceiver is in the Network Termination (NT) located at the customer's end. The term NT refers to network termination functions whether it is an NT1, as shown in Figure 12-23, and/or an NT2 or any other equipment. The NT terminates the DSL on the customer side of the interface shown on Figure 12-23. TR-NWT-000397, *ISDN Basic Access Transport System Requirements*, specifies the ISDN BRA transport system generic requirements. These requirements include provision for *sealing current* on the 2-wire loop, in-service digital error-performance monitoring, metallic and digital testing features, an EOC for LT-NT communications, and interfaces to support systems.

Figure 12-23 also shows the location of the interface of the access line with the NT, which is commonly called the "U" interface point. A standard electrical interface has been internationally established at the "T" reference point. The "T" reference point is a 4-wire interface intended for customer inside wiring, which supports the ISDN BRA service capability and is independent of the transmission technique chosen for the 2-wire loop.

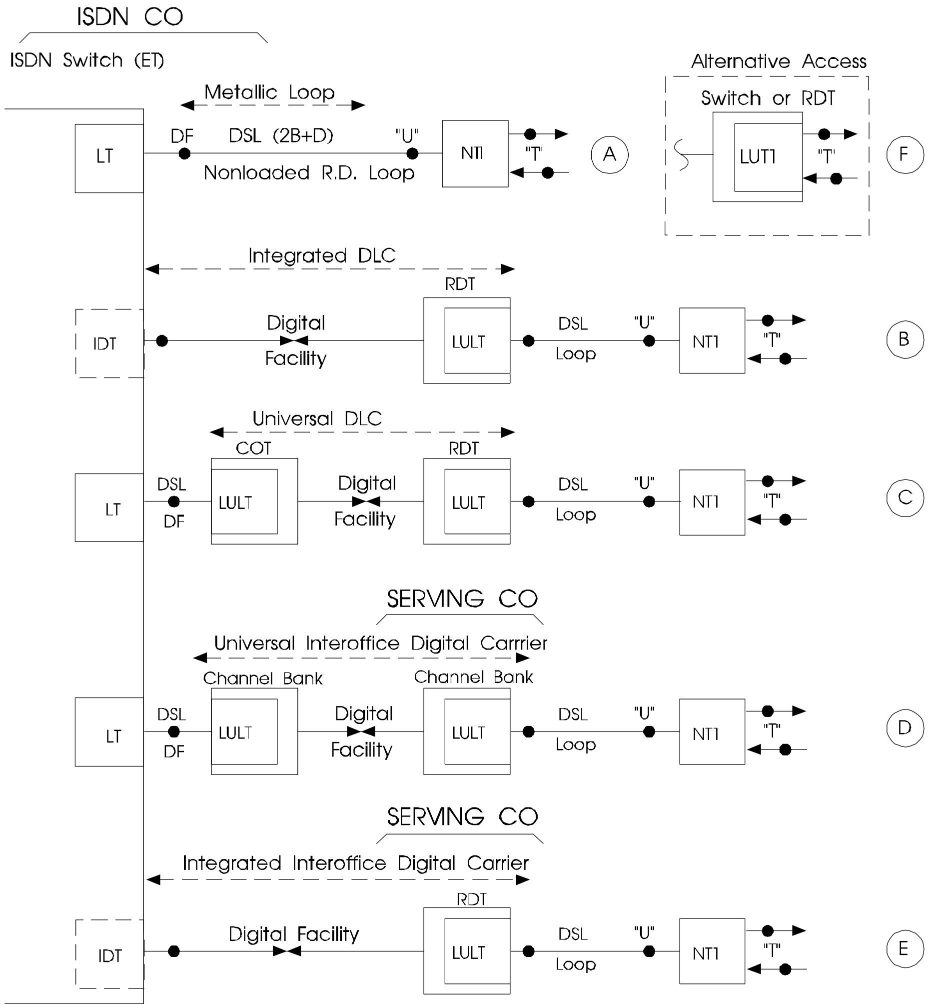
The customer has access to as many as three channels: none, one, or two 64-kbps B (bearer) channels, plus one 16-kbps D channel. The ISDN BRA interface is commonly referred to as 2B+D. These channels provide *clear* transport in the sense that there are no constraints in the transmission of logical information. For instance, there is no limit in the number of consecutive zeros being transmitted. The D channel contains signaling and routing data for the B channels and, possibly, customer packet data. Other than transmission delay (queuing delays), there is no delay to which D channels will be subjected by transport systems over the access path (line segment). In general, the two B channels are transported as independent, byte-oriented 64-kbps channels, without regard for time relationships between the two channels.

Figure 12-25 shows the ISDN BRA architectures, supported in TR-NWT-000397, using the DSL system. The most prevalent architecture is expected to be (A), which consists of a DSL system in which a nonloaded RD loop exists between the LT located at a local ISDN switch and the NT1 located at the customer's premises. The remaining architectures in Figure 12-25 involve the multiplexing of BRA DSLs onto DLC systems or interoffice carrier systems.

TR-NWT-000397 describes two methods of multiplexing and transporting ISDN BRA DSLs over DS1s or higher-rate facilities: 3-DS0 TDM and 4:1 TDM. A 3-DS0 TDM is very simple to implement in carrier systems, as it requires only three *nailed-up* DS0 channels. The ISDN channels (2B+D) are transported transparently in three DS0s. The DSL overhead (16 kbps) is contained in the third DS0 with the D channel. The second method, *4:1 TDM*, is intended for more efficient use of bandwidth in more advanced carrier systems. B channels are assigned DS0s, possibly in real-time upon demand. Up to four D channels share a DS0 on a full-time nonconcentrated basis. The information content of the DSL overhead must be converted for transport to the ISDN switch and operations support systems via the carrier system EOC.

Architectures (B) and (C) in Figure 12-25 illustrate two local BRA architectures involving DLC systems. Architecture (B) shows a DLC system integrated (IDLC) at a DS1 or higher rate with the ISDN switch, and (C) shows a UDLC system multiplexing and transporting BRA DSLs. IDLC access would be the preferred arrangement over UDLC for any significant ISDN demand that cannot be served by simple DSLs directly from the local ISDN switch.

It is unlikely that initial customer demand will necessitate installation of ISDN switching capabilities in every central office, nor is it likely that the network providers would be able to make such a capital investment. Thus, until deployment of ISDN-capable switches is ubiquitous, there will be a need to provide remote access over interoffice carrier systems as shown in access architectures (D) and (E). Interoffice carrier systems can be either universal or integrated like DLC systems.



Legend:

COT	=	Central Office Terminal
DF	=	Distribution Frame
DLC	=	Digital Loop Carrier
ET	=	Exchange Termination
IDT	=	Integrated Digital Terminal
LT	=	Line Termination
LULT	=	Line Unit "LT"
LUNT	=	Line Unit "NT"
LUT1	=	Line Unit "T" Interface
NT1	=	Network Termination 1
R.D.	=	Resistance Design
"T"	=	T Reference Point
"U"	=	U Reference Point

Figure 12-25. ISDN Basic Rate Access Transport Architecture

Other remote access architectures are possible. For example, Remote Switching Units (RSUs) could be hosted in a remote wire center (from an ISDN switch). Also, back-to-back interoffice and loop-carrier systems, interfacing via DSLs across the (non-ISDN) serving central office, could be deployed.

Where cable plant and distance limitations permit, BRA may be provided to a customer via the 4-wire “T” interface. It is also possible that a customer-provided loop regenerator (repeater) may be employed to extend the range of the DSL (for example, customer campus environments).

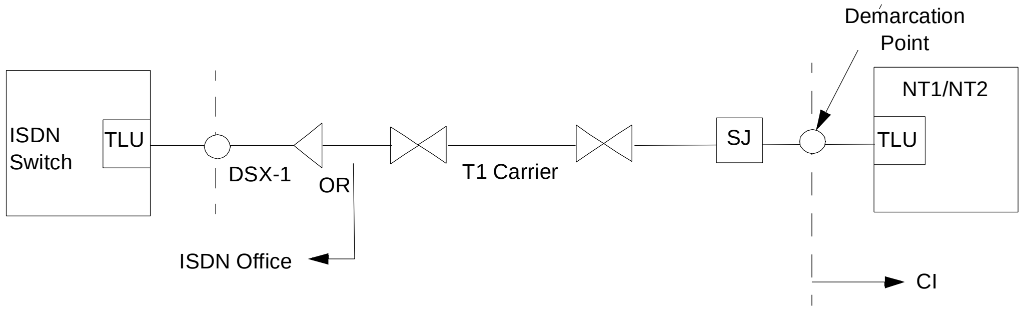
12.9.1.3 Maintenance

The maintenance approach for ISDN BRA lines is based primarily on in-service performance monitoring. The objective of performance monitoring is to ensure that ISDN BRA lines have high levels of availability and quality. This continuous monitoring of the DSL transmission system allows for trouble detection and potential repair of ISDN BRA lines before the customer reports a problem. In-service performance monitoring data aids in verifying and sectionalizing troubles, thereby leading to efficient trouble clearance. Trouble isolation will be done by a combination of standard and ISDN DSL-specific out-of-service maintenance techniques that complement the capabilities of performance monitoring. The out-of-service maintenance techniques include metallic and digital remote-test access.

12.9.2 Primary Rate Access Interface

TR-TSY-000754, *ISDN Primary Rate Access Transport System Requirements*, contains detailed transport requirements for the ISDN PRA interface. The PRA interface is a 4-wire, full-duplex DS1 service interface at 1.544 Mbps to be met at the demarcation point. PRA provides digital network access at the DS1 rate (see Figure 12-26). The PRA interface supports only point-to-point equipment configurations. There is either a transmitter or a receiver for each direction of transmission. The PRA interface uses the ESF for DS1s. The ESF provides for embedded operations channel communications and single-ended performance monitoring capabilities. The framing bit, or 193rd bit in each DS1 superframe, is time-division multiplexed to provide a 4-kbps EOC, a 2-kbps Cyclic Redundancy Check (CRC), and a 2-kbps Framing Pattern Sequence (FPS). If instead of using Bipolar with 8-Zero Substitution (B8ZS), one uses Zero-Byte Time-Slot Interchange (ZBTSI) to provide 64-kbps clear-channel capability, the EOC is reduced to a minimum of 2 kbps. The EOC is used by the service provider to manage and maintain the network.

Figure 12-26 shows the T1-carrier architecture, which is the most common access arrangement in the near term. Figures 12-27 and 12-28 illustrate other transport architectures.



Legend:

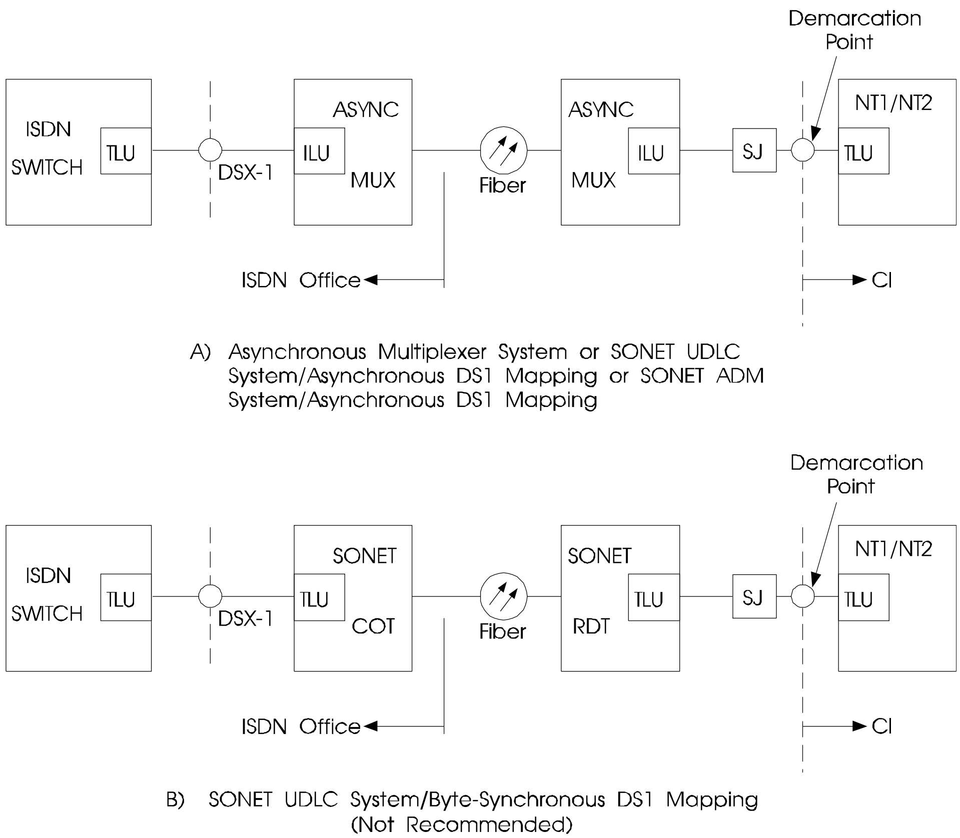
CI	=	Customer Installation
SJ	=	DS1 Interface Connector (Smart Jack)
OR	=	Office Repeater
TLU	=	Terminating Line Unit

Figure 12-26. Primary Rate Access Architecture

PRA service access capability is provided full-duplex within one or more 1.536-Mbps DS1 information payloads. Each DS1 payload is channelized into 24 separate byte-oriented 64-kbps time slots. The most common channelization for PRA will be 23B+D. Since one D channel may provide control and signaling for more than 23 B channels, additional DS1 facility accesses may be provided in the form of 24B. Thus, a given PRA service capability is defined by the D-channel span of control with the channelization possibly occupying the 24th time slot of a PRA facility. The B channels can support virtually any type of service (circuit-switched, packet-switched, or channel-switched).

PRA may be channelized to handle greater information capacity, such as the 384-kbps H0 channel. A PRA with H0-channel capabilities may be provisioned in various combinations with 64-kbps B and D channels on one or more DS1 facilities. Thus, a given PRA may have the form mB+nH0+D (where m and n represent arbitrary numbers).

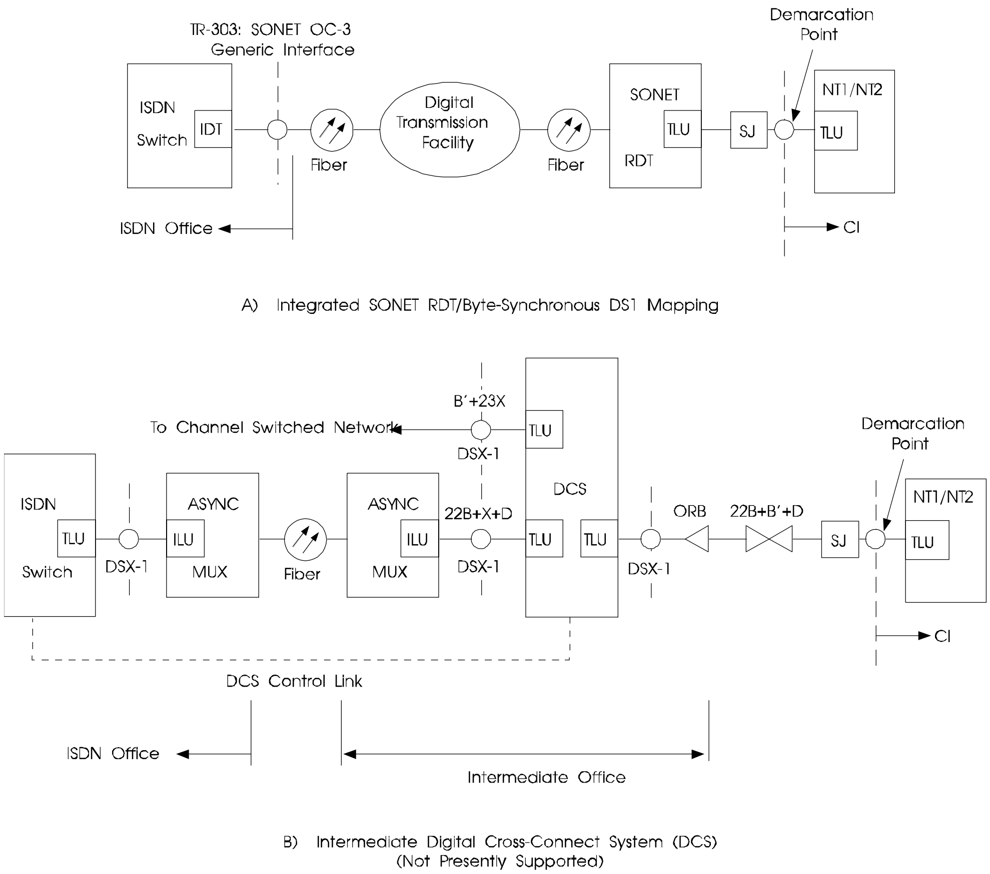
The entire 1.536-Mbps information capacity need not be used in providing a given PRA service capability. Any remaining bandwidth may be used to assign non-ISDN services.



Legend:

ADM	=	Add-Drop Multiplexer
DSX-1	=	Digital Signal Cross-Connect (DS1 Rate)
ILU	=	Intermediate Line Unit
MUX	=	Multiplexer
RDT	=	Remote Digital Terminal
SJ	=	Smart Jack
TLU	=	Terminating Line Unit

Figure 12-27. Other ISDN Primary Rate Access Architectures



Legend:

CI	=	Customer Installation
DCS	=	Digital Cross-connect System
DSX-1	=	Digital Signal Cross-Connect (DS1 Rate)
IDT	=	Integrated Digital Terminal
ILU	=	Intermediate Line Unit
ISDN	=	Integrated Services Digital Network
MUX	=	Multiplexer
ORB	=	Office Repeater Bay
RDT	=	Remote Digital Terminal
SJ	=	Smart Jack
SONET	=	Synchronous Optical Network
TLU	=	Terminating Line Unit

Figure 12-28. Other ISDN Primary Rate Access Architectures

In addition to the 23B+D and the H0-channel applications, the entire information capacity of a DS1 facility (1.536 Mbps) may be used by one single channel, termed an H11 channel. A PRA with H11-channel capabilities would need a D channel (for control and signaling) on a second DS1 facility or perhaps a basic access service capability. When only one DS1 facility is desired by the customer, a reduced version of the H11 channel, called H10, is used. The H10 channel occupies 1.472 Mbps of the available 1.536 Mbps. This permits the 64-kbps D channel signaling and control functions within the same DS1 facility.

12.9.3 Broadband Access

Whereas ISDN BRA and PRA are designed to operate over the copper plant, Broadband ISDN (BISDN) relies mainly on transport over optical fiber facilities. BISDN will provide services and data rates orders of magnitude greater than that of PRA, such as video telephony and very high speed data. International standards groups (ITU-T) have determined that the Asynchronous Transfer Mode (ATM) shall be the vehicle for the delivery of BISDN services. Although the related efforts of the ITU-T primarily focus on developing such ATM standards for BISDN for the public network, it is presently anticipated that ATM will first emerge in the private, business, and corporate environments. Thus, in 1991, the ATM Forum was created to accelerate the development and deployment of ATM products and services in the private environment.

There are currently three options defined for public BISDN transmission:

- Full duplex at 155.52 Mbps
- User to network at 155.52 and network to user at 622.08 Mbps
- Full duplex at 622.08 Mbps.

The ITU-T defines two service areas to be provided by BISDN: Interactive Services and Distribution Services.

Interactive services include:

- Broadband video telephony (e.g., video teleconferencing, video surveillance)
- High speed unrestricted data and information transmission (e.g., Internet)
- Messaging (e.g., video email)
- Retrieval (e.g., medical information, video files).

Distribution services include those with presentation control and those without control. In the former, the centrally located services are transmitted periodically but the customer can control the start and order of the presentation. An example would be for education or training purposes.

Distribution services without presentation control would include broadcast video, characterized by very high quality, high resolution.

Technical Advisory TA-TSV-001238, *Generic Requirements for SMDS on the 155.520 MBPS Multi-Services Broadband ISDN Inter-Carrier Interface (B-ICI)*, was issued in 1992, followed by several generic requirements documents covering broadband switching, signaling, and interfaces, as well as related ATM protocols and network elements; e.g., GR-1110-CORE, *Broadband Switching System (BSS) Generic Requirements*, and GR-1113-CORE, *Asynchronous Transfer Mode (ATM) Adaptation Layer (AAL) Protocols*, both first issued in 1994.

Commercial deployment of ATM and BISDN has been initiated within several areas of the United States, particularly for high speed data.

12.10 Universal Digital Channel

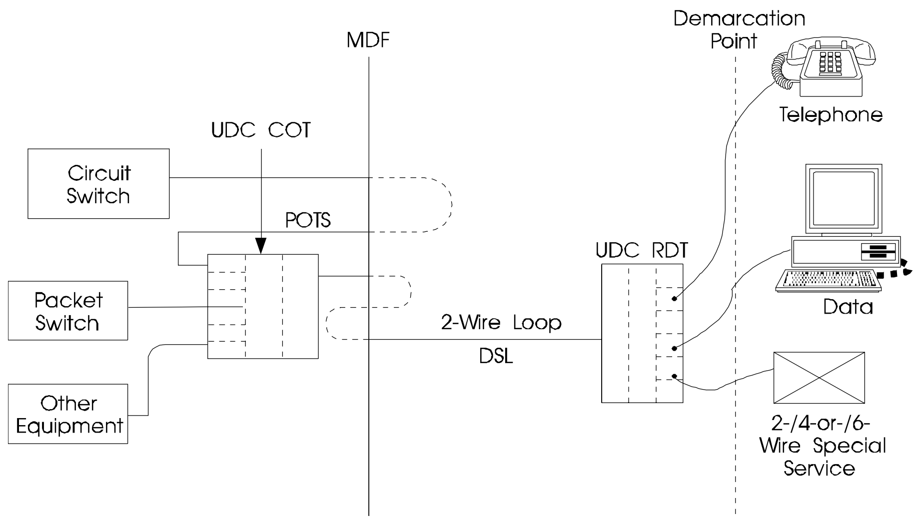
Functionally, the UDC is a small DLC system. It uses the 2-wire DSL transmission technology developed for ISDN BRA (see Section 12.9). UDC systems may be deployed by a LEC to deliver multiple services over a single metallic pair (loop). UDC system requirements and objectives appear in TR-TSY-000398, *Universal Digital Channel (UDC) Generic Requirements and Objectives*.

12.10.1 System Description

A UDC system (see Figure 12-29) consists of a COT, an RDT, and the DSL transport facility. Both the RDT and COT contain the following functional blocks: a DSL transceiver, a channel multiplexer, and as many as six SDMs.

The DSL transceiver develops the electrical interface with the loop and presents to, and accepts from, the channel multiplexer the transmit and receive data streams. Both UDC terminals have matching DSL transceivers that provide 2-wire, full-duplex transmission. The SDMs in the RDT provide the service interfaces to Customer Premises Equipment (CPE). At the central office, corresponding SDMs provide the interfaces to switching systems and/or other transmission systems. The channel multiplexer allocates the bits in the DSL data streams to the services delivered by each SDM and at the central office. It may also provide the interface to network operations systems. Several COTs may be combined in a bay (central terminal) to share an operations interface module for integrated testing, performance monitoring, and provisioning.

Although each of the UDC functional blocks may be implemented as an independent module, most systems have integrated functions and interfaces to minimize system cost and to present a plug-in free environment. Minimization of system cost is of paramount importance. Although some applications may be best suited to a system with plug-ins, the requirements are written to facilitate integration of these functional components within an RDT or COT.



Legend:

DSL	=	Digital Subscriber Line
MDF	=	Main Distributing Frame
POTS	=	Plain Old Telephone Service
UDC COT	=	Universal Digital Channel Central Office Terminal
UDC RDT	=	Universal Digital Channel Remote Digital Terminal

Figure 12-29. Universal Digital Channel

12.10.2 DSL Transmission Technology

The DSL described in TR-NWT-000393 was selected for the UDC to maximize loop coverage, to ease provisioning of the UDC transport facility, to reduce transport equipment costs, and to maximize spectrum compatibility. The DSL can be deployed at up to 18 kft on a nonloaded, resistance-designed (1300 Ω or less) plant. DSL technology can be deployed anywhere within a CSA.

UDC has no relationship to ISDN BRA service capability or interface standards (other than a common transport technology).

12.10.3 Customer-Usable Data Rate

The ISDN BRA DSL provides capacity for two 64-kbps channels and one 16-kbps channel. The 144-kbps total bandwidth of these channels is potentially available for transport of services and could be allocated in various ways. A maximum of six circuits has been proposed for a single UDC system to help simplify system administration. These circuits may be 2-wire, 4-wire, or 6-wire, and either analog or digital.

12.10.4 Transport over Carrier Systems

UDC has been designed to be transportable over any carrier system that meets Telcordia requirements (as specified in TR-NWT-000397) for carrier transport of ISDN BRA. This technical reference places requirements on carrier line units and carrier system features to help ensure that the ISDN carrier transport alternative, termed *3-DS0 TDM*, can be used for UDC.

12.11 Distribution Network Physical Structures

Physical structures support telephone transmission media. These physical structures include poles, towers, conduits, manholes, equipment enclosures such as huts, and even the ground when cable is directly buried.

The most common cable structure is still the pole line. Buried cable is now used wherever feasible, but pole lines remain an important structure in today's environment.

Pole lines carrying critical services are designed with a high strength-to-load ratio, as appropriate for their application environment. Factors such as weather (the frequency, severity, and damaging effects of ice and wind storms) and critical services that may be routed over a pole line determine its design.

According to the load carried and terrain features, poles from 25 to 125 ft are used. Guys or braces support poles where there are unbalanced tensions or changes in the direction of pull. Several kinds of wood (such as southern pine) and preservative treatments are used in the manufacture of "telephone" or utility poles. Suspension strand, used to support cables, has varying breaking strengths from a minimum of 2400 lb to a maximum of 25,000 lb. Self-supporting cable uses built-in strand and requires no separate strand. This simplifies the placing operation.

In rural or suburban areas, cables are often buried directly in the ground. Buried cables generally have a waterproof filling to prevent water intrusion. Splices may be made in the ground or above ground in pedestals. The depth of buried feeder or distribution cables can vary depending upon location, governmental regulations, and the possibility of future excavations such as road widenings or new fences, but is usually from 2 to 4 ft. Service wires or drops are buried relatively shallow, preferably at a minimum of 12 inches. The use of direct-buried innerduct (semi-flexible, high-density polyethylene duct, HDPE, typically 1-2 in. diameter) has been encouraged recently to provide physical protection and facilitate maintenance and upgrades for the distribution and drop media.

In more congested areas, cables are placed in conduit, and manholes are used for splicing. Conduits have a hierarchy: there are main, subsidiary, and branch conduits. Main conduit provides protection for and link feeder sections of plant. Subsidiary conduit links the feeder route to a customer location or distribution plant. Branch conduit links the underground feeder route to the plant (feeder or distribution) that is aerial, attached to a building, or directly buried.

A major advantage of using conduit is the ability to reuse cable spaces without costly excavation by removing smaller, older cables and replacing them with larger cables or fiber facilities. Some companies reserve vacant ducts for maintenance purposes. With the increasing use of relatively small diameter fiber-optic cables, several innerducts are pulled into existing conduit, thus increasing the capacity of the conduit. Thus, several cables may be used within a single conduit.

The length of a conduit section is based on several factors, including the location of intersecting conduits and ancillary equipment such as repeaters or loading coils, the length of cable reels, anticipated pulling tension, and physical obstructions. Conduit sections typically range from 350 to 700 ft in length. Pulling tension is determined by the weight of the cable, the coefficient of friction, and the geometry of the duct run. Plastic conduit has a lower coefficient of friction than does concrete or fiberglass conduit and thus allows longer cable pulls. HDPE innerduct plus lubrication may be used to obtain particularly low frictional values. New placement methods, such as blown-cable techniques, may be effectively used for placing fiber-optic cables relatively long distances within innerduct that is installed within conduit or direct-buried.

When land routing of cables is impractical or impossible, submarine cable is used. Although it is heavily armored, protective material is generally placed on the outside of submarine cable, especially in shallow water. Clamps are used near the water’s edge to anchor the cable from the action of currents.

As loop electronics enters the distribution network, equipment enclosures are becoming more widespread. These enclosures are designed to house repeaters, remote terminals, and other loop electronic equipment. They may or may not have a controlled environment to regulate temperature and humidity. Prefabricated or custom-built huts and housings or cabinets are used in remote areas. In congested areas, or where right of way is difficult to obtain, the underground Controlled Environmental Vault (CEV) provides a dry, temperate underground location for electronic equipment.

12.12 New Technology

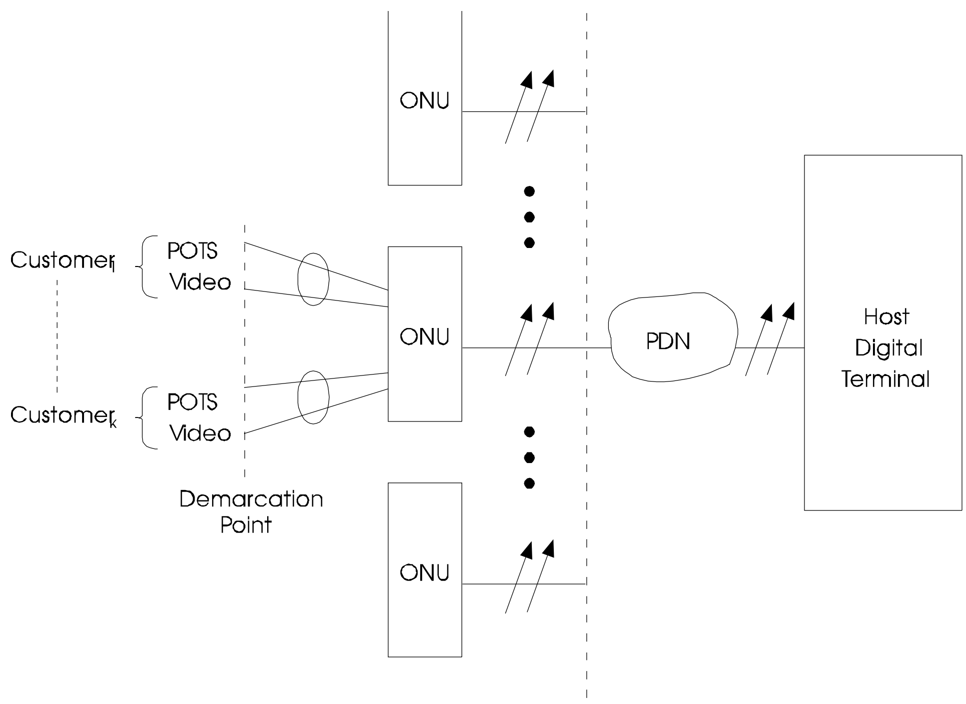
Fiber-in-the-Loop (FITL) in various forms and high speed digital subscriber lines for convenient implementation in the loop distribution plant are complementary maturing loop technologies presently being deployed in the distribution network for providing advanced services.

12.12.1 Fiber-in-the-Loop

FITL represents a transport technology that not only provides end-to-end digital connectivity, but also lowers provisioning costs for existing services and allows the gradual introduction of new broadband services, such as video services. FITL includes Fiber-to-the-Curb (FTTC) as well as Fiber-to-the-Home (FTTH) and other variations.

Requirements for FTTC systems are contained in GR-909-CORE, *Generic Requirements and Objectives for Fiber in the Loop Systems*, including video requirements in addition to narrowband service requirements. Initially, FTTC systems will be treated as *black boxes*. The interior of the black box is described in terms of functional requirements, while its interfaces to customers and to the remainder of the local access network will be specified in detail. As the technology matures, optical interfaces may be defined to attain a mix-and-match capability among different manufacturers. This approach to generic requirements allows service providers to deploy FTTC systems independently of other systems present in the serving central office.

The FTTC system consists of an Optical Network Unit (ONU), an optical fiber Passive Distribution Network (PDN), and a Host Digital Terminal (HDT) (see Figure 12-30).



Legend:

ONU	=	Optical Network Unit
PDN	=	Passive Distribution Network
POTS	=	Plain Old Telephone Service

Figure 12-30. Generic Fiber-in-the-Loop (FTTC) System

The ONU is a network element that serves several living units, and provides existing service interfaces to residential and small business customers. The ONU is connected to the individual living units by service lines or drops consisting of metallic twisted pairs and coaxial cable. The optical fiber distribution network connects the ONU to the HDT, which provides concentration, grooming of services, signaling, and operations functions. The HDT may be located in a central office, in the feeder, or in the distribution segments of the access network. FTTC systems are being commercially deployed in several parts of the country, primarily in growth areas.

FTTH is similar to FTTC, but utilizes an Optical Network Terminal (ONT) located at the residence, allowing complete elimination of metallic media from the loop distribution plant. Cost-effective technologies for implementing FTTH are being developed and investigated for deployment in the near future.

An additional architecture currently in common use is that of Hybrid Fiber-Coax (HFC), which incorporates coaxial distribution cable and line extenders. The coaxial cable is used as the primary transmission medium connecting an Optical/Electrical Node (O/E N), serving a community, to terminals serving several living units each and connected to the individual residences by coaxial drops. An arrangement presently being deployed in some areas is the parallel installation of FTTC and HFC. In this case, the FTTC network provides narrowband services, and the HFC network provides broadcast video.

12.12.2 Digital Subscriber Lines

Advances in digital signal-processing techniques have been made to extend the capability of the embedded copper plant. First generation DSL technology was introduced with the development of HDSL. This technology was used to supplement T-1 carrier delivery systems. The next phase of DSL development introduced ADSL, which expanded the capability of the twisted cable pair, so that it is possible to transport signals in excess of 1.5 Mbs over non-conditioned, non-repeatered, POTS-like unloaded loops out to CSA range.

Advances with DSL technology produced ADSL “G-Lite”, which provides 512 Kbs upstream and 1.54 Mbs downstream without using POTS splitters. Technology improvements also produced Rate Adaptive DSL (RADSL), where the hardware adjusts data throughput based on the length and quality of the loop. As DSL technology advances, the terms Very High Rate DSL (VDSL) and xDSL are used to describe DSL delivery data rates that exceed 6.3 Mbs.

DSL technology standards, which would permit interoperability among vendors, are currently being developed. Some ADSL standards exist while all of the more recent advancements with this technology are just now being considered for standardization by the appropriate committees.

12.12.2.1 High Bit-Rate Digital Subscriber Line (HDSL)

An HDSL system represents a robust, network-provided transparent alternative for a T1 line, so that the customer does not have to effect any change to maintain the existing service. It may be represented by a pair of High Bit-Rate Transmission Units (HTUs), known as central office HTU (HTU subcentral office) and a Remote Distribution HTU (HTU subRD), and two twisted-wire pairs connecting them (see Figure 12-31). The robustness of HDSL allows its use without bridged-tap removal, without binder group separation or strict shielding requirements such as typically required for T1 lines, and without repeaters up to 12,000 ft. An HDSL line consists of two bidirectional pairs; each pair transmits half of the DS1 rate. Preliminary requirements for HDSL transmission technology and associated operations have been provided in TA-NWT-001210, *Generic Requirements for High-Bit-Rate Digital Subscriber Lines*, and FA-NWT-001211, *Generic Network Operations Requirements for High-Bit-Rate Digital Subscriber Lines*, respectively. HDSL is presently being deployed as an alternative to T1 lines and providing DS1 service to subscribers

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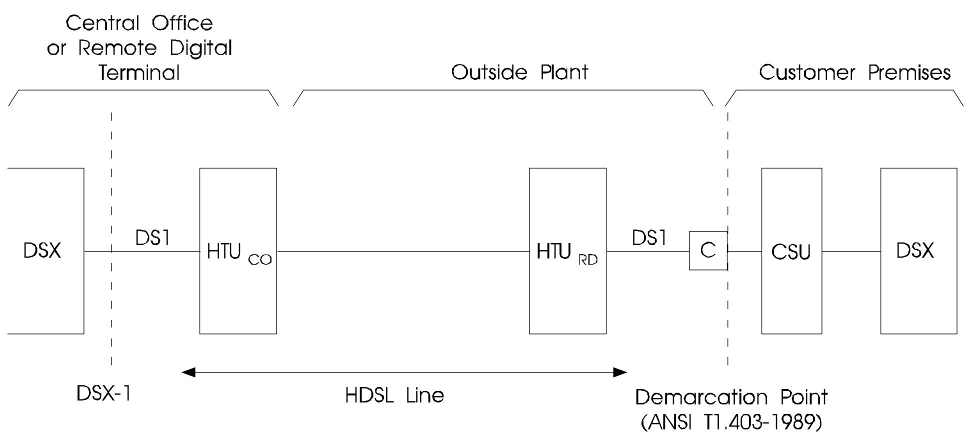

Legend:

C	=	DS1 Connector
CSU	=	Customer Service Unit
DSX	=	Digital Signal Cross-Connect
DS1	=	Digital Signal level 1
HTU_{CO}	=	Central Office HTU
HTU_{RD}	=	Remote Distribution HTU

Figure 12-31. Repeaterless DS1 Access Architecture Using HDSL

12.12.2.2 Asymmetric Digital Subscriber Line (ADSL)

ADSL technology utilizes a single non-loaded copper pair that conforms to RRD rules (see Section 12.1) to transport a unidirectional, high bit-rate channel (1.544 Mbps and higher), bidirectional lower bit-rate channel(s), and a POTS line. The target range for ADSL is 18,000 ft.

ADSL-1 technology limits the high bit-rate to 1.544 Mbps, whereas ADSL-3 technology make it possible to transport higher bit-rates. Thus, ADSL-1 provides a 1.544-Mbps channel to the subscriber, a 16.0-kbps bidirectional low bit-rate channel, and a POTS line. ADSL-3 uses techniques in adaptive filtering, parallel processing, channel coding, and Very Large Scale Integration (VLSI) to transmit higher bit-rates over twisted pairs than previously possible. It provides a composite 6.312 Mbps unidirectional video signal from the Central Office to the customer, a 64-kbps bidirectional control signal, a 160-kbps bidirectional ISDN BRA signal, a 384-kbps bidirectional ISDN PRA H0 signal, and a POTs line. ADSL-3 is designed to build on SONET standards.

The ADSL equipment consists of ADSL Terminal Units (ATUs) connected by a single non-loaded twisted pair. The ATU terminal located at the CO is designated as the ATU-C, and the one at or near the customer is the ATU-R. These terminals multiplex/demultiplex the various signals for transport over the copper line. A POTS splitter resides in the ATU-C and the ATU-R and consists of filters to separate the 300-Hz to 3-KHz voice channel from the upstream and downstream channels. The POTS splitter not only passes the voice frequency signal, but also the dial tone, ringing, and on/off hook signals. Automated POTS test systems are able to test the baseband circuit.

ADSL technology provides the LECs the capability to offer a variety of new services to customers by using the embedded copper plant. It will enable them to enter a strategically important market that includes Pay-Per-View and Video-on-Demand applications for the residential subscribers. For business customers, ADSL technology will help the LECs provide services such as targeted advertising, home shopping, high-quality audio, interactive data, and multimedia applications. In general, ADSL is expected to stimulate the demand for high bit-rate services, which new revenues can be used to help drive fiber deployment and thus further stimulate growth of broadband services. Early preliminary requirements for ADSL transmission technology and associated operations are provided in FA-NWT-001307, *Framework Generic Requirements for Asymmetric Digital Subscriber Lines*, and FA-NWT-001308, *Framework Generic Network Operations Requirements for Asymmetric Digital Subscriber Lines*, respectively.

12.12.2.3 VDSL/xDSL Current Advancements

The terms VDSL and xDSL are generally used interchangeably to describe the latest version of DSL technology. The latest versions are constantly increasing the data rates and distances over which these rates can operate. Currently, up to 30 Mbs of data throughput can be achieved downstream from the LEC to the customer with up to 3 Mbs of upstream throughput. Loop lengths up to 3 Kft currently can support these data rates. These advancements enable substantial video and/or data access to subscribers over the traditional loop plant.

This technology now enables LECs to enter the video delivery market without the “last mile” fiber optic cable and hardware costs. While DSL technology does not offer the same bandwidth equivalent of a fiber delivery platform, it can be used to “secure” a video customer base, which could then be migrated to a fiber system based on economics.

12.13 The Unbundled Loop Environment

This section provides an overview of the unbundled loop environment. It first presents background information to identify key regulatory mandates relating to whole loop and sub-loop unbundling. It then describes common configurations and options for unbundling whole loops that are served by all-copper facilities, UDLC systems, and IDLC systems, and addresses various transmission and technical issues associated with unbundled loops. Finally, it assesses the evolving loop unbundling environment in terms of quantity, quality, and types of unbundling.

12.13.1 Regulatory Mandates for Whole Loop and Sub-Loop Unbundling

The Telecommunications Act of 1996 passed by Congress defined seven Unbundled Network Elements (UNEs) that Incumbent LECs (ILECs) must unbundle and offer to Certified/Competitive LECs (CLECs). This law requires these network elements to be offered to competitors in a non-discriminatory manner and have quality equal to the same facilities that the ILEC itself uses.

The seven UNEs defined in the Telecom Act of 1996 are:

1. Local Loops
2. Network Interface Devices (at the customer premises)
3. Local and tandem switches
4. Interoffice transmission facilities
5. Operations Support Systems (OSSs)
6. Call routing signaling databases
7. Operator/directory services.

A local (whole) loop is defined as the transmission facility between the ILEC central office Main Distributing Frame (MDF), or its equivalent, and the Network Interface Device (NID) at the customer premises. Unbundled loops may be provided using a variety of transmission technologies including, but not limited to: copper wire, copper wire-based DLC, and fiber-optic DLC systems. Such technologies can be used singularly or in tandem to provide an unbundled loop.

Subsequent to the passing of the Telecommunications Act of 1996, the ILECs sought judicial relief and won an appeal at the U.S. Eighth Circuit Court to repeal the UNE mandates. Upon appeal by the FCC and CLECs, the U.S. Supreme Court issued its "FCC Remand Order," which required the FCC to re-examine all seven UNEs and justify/explain the rationale for each UNE that the FCC considers necessary.

In November 1999, the FCC released its Docket 99-238, which eliminated the Operator/Directory Services UNE, but retained the other six UNEs. In addition, the FCC added a new UNE called "Sub-Loop". A sub-loop unbundled network element refers to any portion of the ILEC's whole loop which is outside the central office and that a CLEC can access and make interconnection to offer service to a customer.

In December 1999, the FCC released its Docket 99-355, which mandated another UNE, this one relating to the high-frequency portion of the loop. The mandate requires line sharing arrangements between an ILEC and a CLEC for both whole loop and sub-loop unbundling configurations. Line sharing, which is also known as spectrum unbundling, refers to the same twisted copper pair being used by more than one carrier. The ILEC can carry traditional voice-switched telephone service within the 0- to 3-Khz spectrum, and the CLEC can provide DSL services over the spectrum above 3 Khz. All ILECs must begin line sharing implementations by mid-year 2000.

12.13.2 Loop Unbundling

There are two main types of loop unbundling. The first is called "whole loop" unbundling, which is the unbundling of a whole loop from the MDF in the ILEC's central office to the customer premises. The second type is called "sub-loop" unbundling, which refers to a portion of the ILEC's whole loop being offered to a CLEC. This section provides more information about each type of loop unbundling.

12.13.2.1 Whole Loop Unbundling Configurations

Typically, when a customer requests dial tone service from a CLEC, the ILEC removes the wired connection to the ILEC switch in the central office and rewires the customer's loop to a CLEC "meet" point in the central office. Figure 12-32 depicts whole loop transfers in the ILEC central office when the customer is served by copper facilities or by a UDLC system. In most cases, there is an analog handoff to the CLEC. If the CLEC requests a digital handoff, the ILEC may utilize a D4 channel bank to digitize the circuits. Most CLECs transport the unbundled loops back to their central offices (switches) using GR-303 IDLC systems. To do this, the CLECs deploy GR-303 RDTs within their collocation cages in the ILEC's central offices.

The most critical factor associated with unbundling a customer loop is the type of loop facility that the customer is already utilizing for service, such as all-copper, UDLC system, or IDLC system.

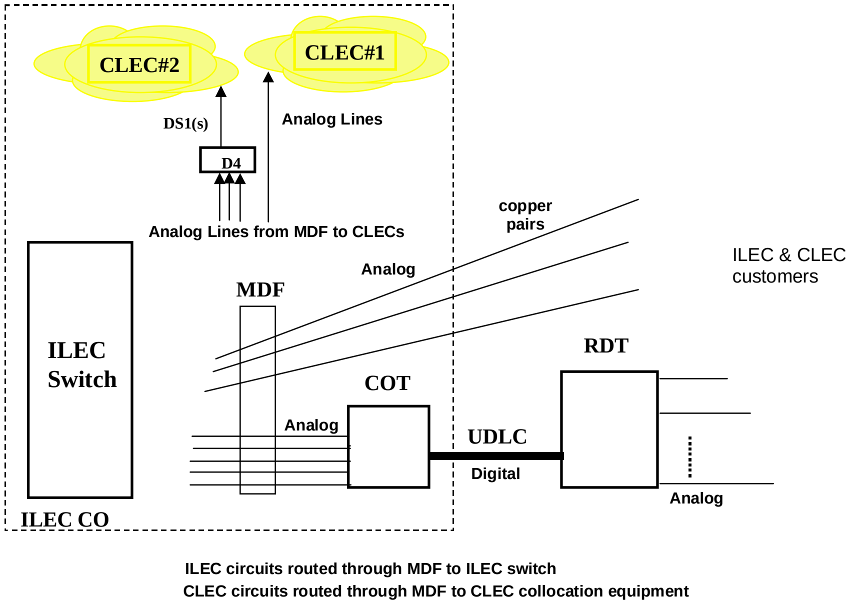

Figure 12-32. Unbundling Loops Served by Copper or UDLC Systems

- If the customer is receiving service over all-copper facilities, the transfer of the whole loop is straightforward as indicated in Figure 12-32. The ILEC removes the central office connection to its switch and places a jumper from the MDF to the meet point at the CLEC's collocation cage. There is no need to rewire the outside plant or visit the customer premises.
- If the customer is receiving service over a UDLC system, the transfer of the whole loop can be straightforward as shown in Figure 12-32. The ILEC removes the central office connection to its switch and places a jumper from the MDF to the meet point at the CLEC's collocation cage. Again, there is no need to rewire the outside plant or visit the customer premises.
- However, if the customer is served by an IDLC system, the loop is digitally transmitted to the ILEC switch. There are a variety of "technically feasible" options available to the ILEC to unbundle the loop. Each ILEC has established its own set of approved unbundling options along with the corresponding methods, procedures, and practices needed for implementing these options. Numerous unbundling options are possible because many of today's RDTs support multiple kinds of interfaces such as: GR-303, TR-08, UDLC, and D4 DS1. Also, some RDTs are capable of supporting multiple GR-303 Interface Groups, thereby permitting a single RDT to connect to multiple switches.

  Some common IDLC unbundling options are:

  1. Bypass the IDLC system and transfer the loop to an all-copper pair

     If there are available spare copper facilities serving the customer's neighborhood, transferring the IDLC customer to a spare all-copper circuit may be a viable option for the ILEC, as shown in Figure 12-33. Although this

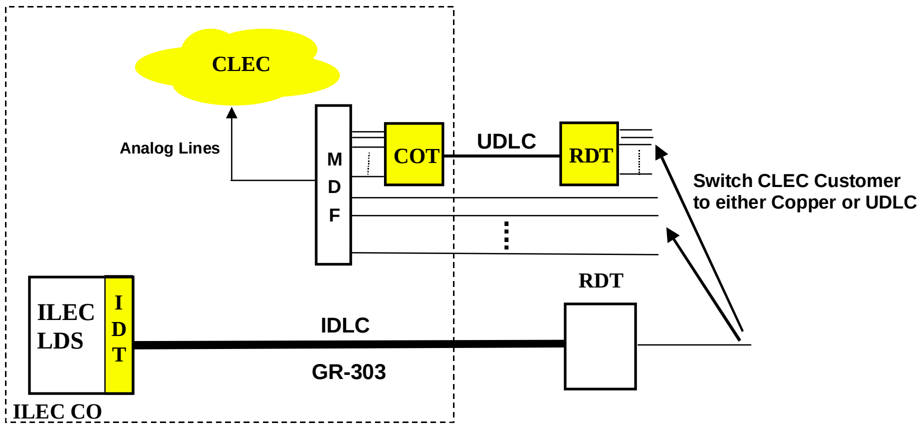

Figure 12-33. IDLC Unbundling - Bypass the IDLC System

procedure is relatively simple, it requires central office and outside plant rewiring to complete the new circuit from the MDF to the customer. The all-copper unbundled loop is the easiest unbundling architecture for the ILEC to perform maintenance and testing.

Some ILECs serve new neighborhoods/housing developments with DLC systems and install a very limited number of copper pairs to support certain services. In these areas, spare copper facilities can be quickly exhausted if used for unbundled loops.

2. Bypass the IDLC system and transfer the loop to a UDLC system

   If there are no spare copper facilities in the customer's neighborhood, the ILEC may transfer the customer's circuit from the IDLC system to a UDLC system (see Figure 12-33). This transfer will also involve both central and outside plant work activity.

   The customer fill rates at IDLC/UDLC CEV sites are typically 50 to 70%. There is a moderate amount of spare capacity on the UDLC systems to support transfers from IDLC systems.

3. Utilize the UDLC capability of the IDLC system

   If the IDLC system is equipped to support UDLC functionality, the ILEC can electronically re-provision the circuit from IDLC to UDLC (see Figure 12-34). No outside plant work activity is needed. Central office work activity is needed to run jumpers from the MDF to the collocation cage and, if necessary, place a UDLC plug-in at the COT.

4. Utilize a separate GR-303 Interface Group for the CLEC customers

   Figure 12-35 shows the use of separate GR-303 Interface Groups to carry ILEC and CLEC traffic. The RDT must support the MIG (Multiple Interface Group) capability defined in the GR-303 specification. This configuration allows a CLEC switch to connect to the ILEC's RDT at the GR-303 interface level.

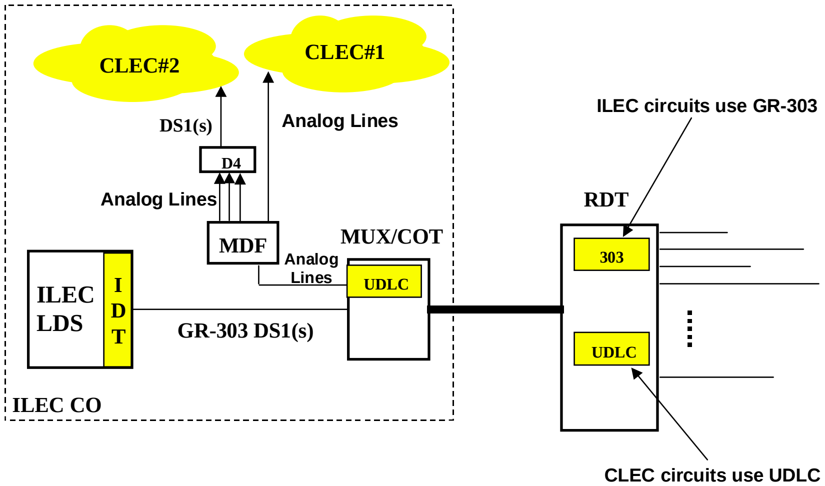

Figure 12-34. IDLC Unbundling Using the UDLC Capability of RDT

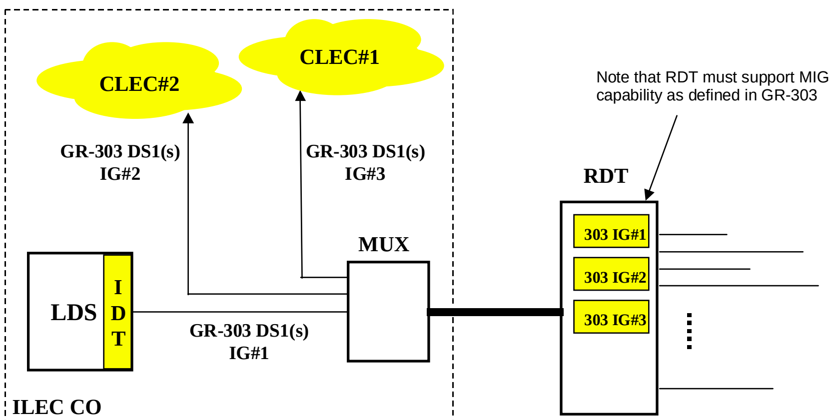

Figure 12-35. IDLC Unbundling Using Separate GR-303 Interface Groups

This arrangement may be cost effective for those CLECs having a “critical mass” of subscribers served by the RDT or group of RDTs in a CEV. Since the GR-303 Interface Group supports operations functionality, there are a variety of issues (provisioning, alarm reporting, sharing of test resources, etc.) that are currently being addressed by the industry.

In response to the Telecommunications Act of 1996, GR-303 requirements were changed in 1997 to permit a single DS1 to be called a 303 Interface Group. A minimum of two DS1s was previously required. This change allows a CLEC to serve a small base of customers at an RDT more economically (but at the risk of lower service availability and reliability).

5. Share a GR-303 Interface Group and use the sidedoor port of the switch to transport CLEC traffic out of the ILEC switch

Figure 12-36 shows the use of a GR-303 Interface Group sharing ILEC and CLEC traffic where all CLEC traffic is routed through sidedoor port DS1s out of the ILEC's switch.

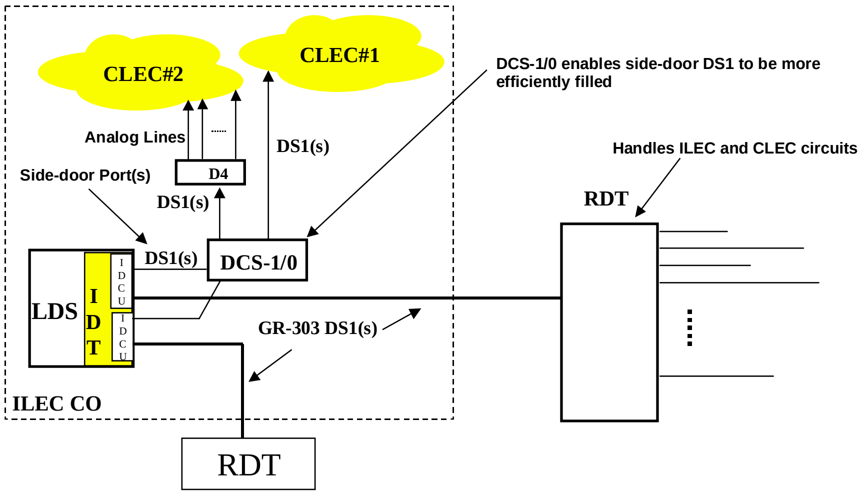

Figure 12-36. IDLC Unbundling Using Sidedoor Port

CLEC circuits are provisioned as non-switched, non-locally switched circuits within the IDLC system. While the DCS-1/0 is shown in the figure, it is not a requirement of this architecture. The advantage of using a DCS-1/0 is realized if the CLEC is not fully utilizing a DS1 from the ILEC LDS to the CLEC, and multiple switch modules with IDCUs are used by the ILEC. If a DCS-1/0 is placed between the LDS DS1 sidedoor port and the CLEC DS1s, it would permit full utilization of the sidedoor LDS/IDCU hardware by enabling CLEC DS0s to be rearranged in the DCS-1/0 and placed on the individual CLEC DS1s.

The ILEC must address the following issues associated with the sidedoor port arrangement:

A. The cost of a DS1 switch termination for a sidedoor port is about ten times the cost for a DS1 line card on a RDT.

B. Since each CLEC circuit requires a nailed up DS0, the ILEC may encounter blocking over the IDLC system as other circuits compete for DS0 channels.

C. The number of sidedoor ports that can be engineered varies depending on the LDS supplier.

D. There is limited support in existing special services design systems and databases to support sidedoor port circuits.

E. The ILEC may need field visits to install special service D4 channel units at the RDT.

6. Utilize separate TR-08 Interface Groups to transport CLEC traffic

   Figure 12-37 shows the use of separate TR-08 Interface Groups to carry CLEC traffic while utilizing the GR-303 Interface for ILEC traffic. In the figure, the RDT supports both GR-303 and TR-08 generic interface capabilities. CLEC switches can interconnect with the ILEC's RDT utilizing the DS1 handoff from the TR-08 interface.

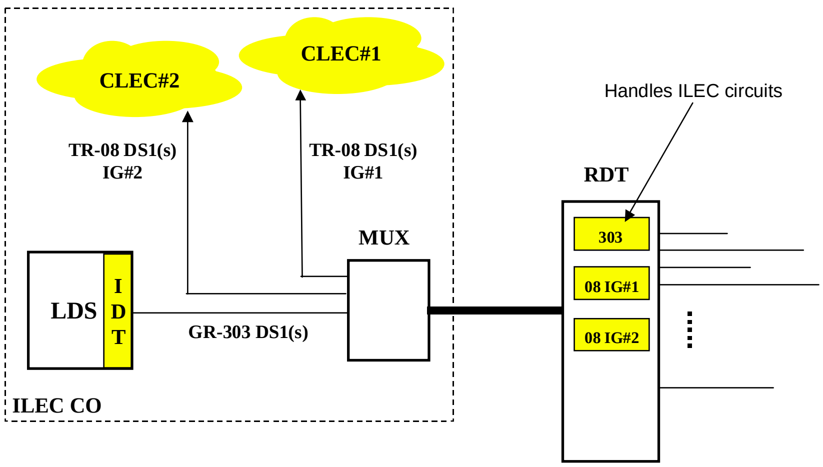

Figure 12-37. IDLC Unbundling Using Separate TR-08 Interface Groups

7. CLEC leases entire RDT

   Figure 12-38 shows the configuration when a CLEC leases an entire RDT from the ILEC.

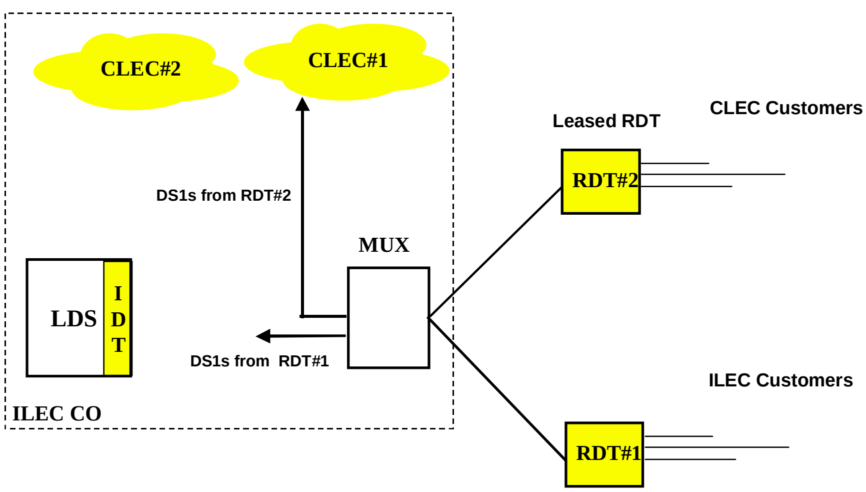

Figure 12-38. IDLC Unbundling - CLEC Leases Entire RDT

RDT#1 serves the ILEC customers, and RDT#2 serves the CLEC customers. This unbundling option may be cost-effective for the CLEC if the CLEC has a significant number of residential customers in the neighborhood or is serving a business park or campus.

12.13.2.2 Sub-Loop Unbundling Configurations

Sub-loop unbundling occurs when a CLEC interconnects to a loop facility at a point outside the ILEC's central office. The Sub-Loop UNE is defined by the FCC as portions of the loop that can be accessed at terminals in the ILEC's outside plant. An accessible terminal is a point on the loop where technicians can access the wire or fiber within the cable without removing a splice case to reach the wire or fiber within. Examples of access terminals are: poles, pedestals, the NID, the Minimum Point Of Entry (MPOE) to the customer premises, the MDF, and the Feeder/ Distribution Interface (including CEVs, utility rooms, and DLC Remote Terminals). Figure 12-39 shows sub-loop unbundling at a GR-303 Remote Terminal (RDT) where a CLEC interconnects at the ILEC's RDT using its own GR-303 Interface Group facilities to provide service to its customers. In this configuration, the CLEC leases from the ILEC the RDT equipment and the RDT line facilities to each of its customer premises.

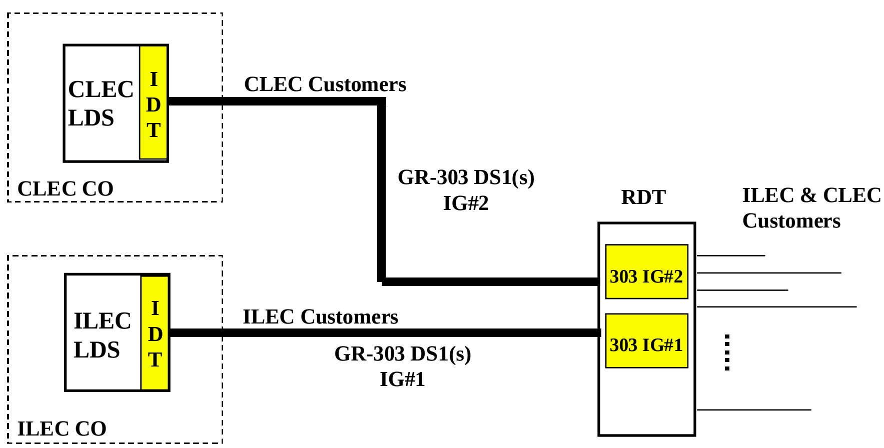

Figure 12-39. Sub-Loop Unbundling at an RDT

The FCC mandate on sub-loop network elements places the burden on each state regulatory commission to determine whether specific interconnection points in the outside plant are "technically feasible". The law directs the state commission to examine the ILEC's specific architecture and the specific technology used over the loop to determine whether it is really technically feasible to unbundle the sub-loop at a potential access point where a competing carrier requests access. Two key factors that are considered in this "technically feasible" determination are whether there is adequate space for collocated CLEC equipment to be installed and if the site has sufficient security safeguards to prevent mischief or sabotage. The FCC has indicated that its central office collocation rules are also applicable to collocation in outside plant locations.

Since the FCC sub-loop unbundling mandate was announced in 1999, there has been little time for ILECs, CLECs, and state commissions to deal with this UNE. Sub-loop UNEs are an emerging market and, at this time, it is not clear which portions of the ILEC outside plant will be aggressively pursued by CLECs.

Numerous sub-loop unbundling configurations are possible. A CLEC may lease facilities from multiple carriers to create circuits, or it may deploy some of its own facilities and lease other facilities to extend its network to reach a greater customer base. Depending on the CLEC's network architecture, some of the transmission and technical issues associated with IDLC and UDLC configurations (described in Section 12.13.3) may be observed.

12.13.3 Unbundling Issues Associated with UDLC and IDLC Systems

There are various transmission and other technical issues associated with the use of UDLC and IDLC systems in the unbundling environment. In many loop unbundling configurations, the CLEC utilizes an IDLC system to economically transport unbundled loops from the ILEC's central office to the CLEC's central office. Issues arise when the ILEC terminates long length all-copper loops or DLC-transported loops to the CLEC's RDT (meet points at the collocation cage).

When an unbundled all-copper loop greater than 900 ohms or 12 Kft long is terminated at the CLEC's RDT, the customer may encounter degraded voice frequency transmission. To maintain the POTS grade of service, the CLEC may need to install an RDT line unit with a higher DC supervisory range to accommodate the long loop.

When an unbundled UDLC loop is terminated at the CLEC's RDT, the following impacts may be observed:

— Increased dial tone delay

— Degradation of on-hook transmission services, such as caller ID (due to delays)

— Degradation of signal quality (as a result of multiple A/D and D/A conversions)

— Reduction in analog modem operation speed (connection speed depends on loop length, number of A/D conversions, local switch type, and interoffice facility type).

Figure 12-40 shows the back-to-back DLC configuration.

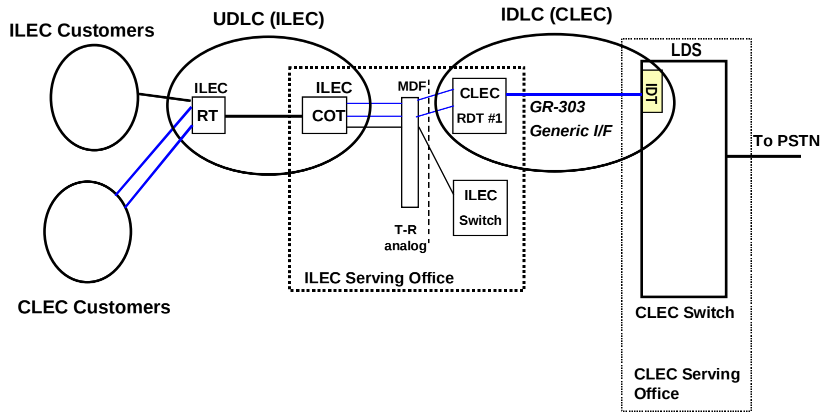

Figure 12-40. ILEC/CLEC Back-To-Back DLC Configuration

12.13.4 The Evolving Loop Unbundling Environment

Initially, ILECs offered and provided unbundled circuits to CLECs as analog handoffs to the collocation cages of the CLECs. Many ILECs now offer DS-0 digital connectivity to the CLEC collocation cages. DS-1 interconnection is emerging. Less than 2% of all access lines in the U.S. are currently unbundled, but this may rise to as much as 30% in the next 5 to 10 years. The factors that will significantly impact the potential growth in unbundled loops are: additional FCC regulatory/court changes, rate of implementation of ILEC/CLEC line sharing, and decisions by individual state commissions.

In the current loop unbundling environment, CLECs are largely focusing on unbundling ILEC business customers. The drivers behind this approach are economics and scalability. Provisioning and maintaining multiple unbundled loops from a single business customer lets the CLEC use digital subscriber lines over ILEC facilities. CLECs are requesting copper unbundled pairs and placing DSL equipment on these pairs to provide multiple POTS lines over no more than two unbundled copper pairs. The residence unbundling architecture presents a greater economic challenge to the CLEC because residential customers will generally request a single unbundled loop. CLECs find serving business customers much more profitable than serving residential customers. The FCC mandates on sub-loop unbundling and line sharing are expected to have a significant impact on CLEC expansion into the xDSL marketplace because CLECs will no longer be forced to incur the full cost of a separate copper line to serve customers.

The FCC orders mandating sub-loop unbundling and line sharing will likely be challenged in the courts. While this process evolves, CLECs will press for access to the local loop at the interconnection point nearest to the customer. When DLC systems are used to provide ILEC services, the CLEC will want to interconnect at the RDT. The reasoning for gaining access to the RDT on the analog customer side is to have the ability to provide all of the offered ILEC services without the transmission impairments and operational issues associated with interconnection at any other location.

When these RDTs are within 3,000 feet of the customer, either the ILEC or CLEC can have the ability to use xDSL technology to offer high-speed data access as well as video services. The CLEC may also choose to offer traditional telephone services using “voice over IP” technology. With this technology, it is possible to have the ILEC owning the 0- to 3-khz bandwidth on a twisted pair from the RDT to the customer NID and having no services connected at the customer premises. The CLEC utilizes the frequency above 3 kHz (xDSL) and provides voice, data, and video services.

The evolution of the loop plant is shifting toward greater fiber deployment. When fiber systems advance to the situation where a significant number of residences are served using FTTC systems, CLECs will request access to some of the interconnection points in the fiber network.